

CHAPTER 0: INTRODUCTION TO COMPUTING
SECTION 0.1: NUMBERING AND CODING SYSTEMS

1.

- (a) $12_{10} = 1100_2$
- (b) $123_{10} = 0111\ 1011_2$
- (c) $63_{10} = 0011\ 1111_2$
- (d) $128_{10} = 1000\ 0000_2$
- (e) $1000_{10} = 0011\ 1110\ 1000_2$

2.

- (a) $100100_2 = 36_{10}$
- (b) $1000001_2 = 65_{10}$
- (c) $11101_2 = 29_{10}$
- (d) $1010_2 = 10_{10}$
- (e) $00100010_2 = 34_{10}$

3.

- (a) $100100_2 = 24_{16}$
- (b) $1000001_2 = 41_{16}$
- (c) $11101_2 = 1D_{16}$
- (d) $1010_2 = 0A_{16}$
- (e) $00100010_2 = 22_{16}$

4.

- (a) $2B9_{16} = 0010\ 1011\ 1001_2, 697_{10}$
- (b) $F44_{16} = 1111\ 0100\ 0100_2, 3908_{10}$
- (c) $912_{16} = 1001\ 0001\ 0010_2, 2322_{10}$
- (d) $2B_{16} = 0010\ 1011_2, 43_{10}$
- (e) $FFFF_{16} = 1111\ 1111\ 1111\ 1111_2, 65535_{10}$

5.

- (a) $12_{10} = 0C_{16}$
- (b) $123_{10} = 7B_{16}$
- (c) $63_{10} = 3F_{16}$
- (d) $128_{10} = 80_{16}$
- (e) $1000_{10} = 3E8_{16}$

6.

- (a) $1001010 = 0011\ 0110$
- (b) $111001 = 0000\ 0111$
- (c) $10000010 = 0111\ 1110$
- (d) $111110001 = 0000\ 1111$

7.

- (a) $2C+3F = 6B$
- (b) $F34+5D6 = 150A$
- (c) $20000+12FF = 212FF$
- (d) $FFFF+2222 = 12221$

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 3

8. (a) $24F-129 = 126_{16}$

(b) $FE9-5CC = A1D_{16}$

(c) $2FFFF-FFFFF = 30000_{16}$

(d) $9FF25-4DD99 = 5218C_{16}$

9. (a) Hex: 30, 31, 32, 33, 34, 35, 36, 37, 38, 39

(b) Binary: 11 0000, 11 0001, 11 0010, 11 0011, 11 0100, 11 0101, 11 0110, 11 0111, 11 1000, 11 1001.

ASCII (hex) Binary

0 30 011 0000

1 31 011 0001

2 32 011 0010

3 33 011 0011

4 34 011 0100

5 35 011 0101

6 36 011 0110

7 37 011 0111

8 38 011 1000

9 39 011 1001

10. 000000 22 55 2E 53 2E 41 2E 20 69 73 20 61 20 63 6F 75 "U.S.A. is a cou

000010 6E 74 72 79 22 0D 0A 22 69 6E 20 4E 6F 72 74 68 ntry"..in North

000020 20 41 6D 65 72 69 63 61 22 0D 0A America"..

SECTION 0.2: DIGITAL PRIMER

11.

A
B
C
1
2
3
4
5
6

12.

A B C Y

0 0 0 0

0 0 1 1

0 1 0 1

0 1 1 1

1 0 0 1

1 0 1 1

1 1 0 1

1 1 1 1

4

13.

.

14.

A B C Y

0 0 0 0

0 0 1 0

0 1 0 0

0 1 1 0

1 0 0 0

1 0 1 0

1 1 0 0

1 1 1 1

15.

16.

A B C Y

0 0 0 1

0 0 1 1

0 1 0 1

0 1 1 1

1 0 0 1

1 0 1 1

1 1 0 1

1 1 1 0

A B C Y

0 0 0 0

0 0 1 1

0 1 0 1

0 1 1 0

1 0 0 1

1 0 1 0

1 1 0 0

1 1 1 1

1

2

3

4

5

6

C

A

B

1

2

3

4

5

6

B

A

C

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 5

17.

A B C Y

0 0 0 1

0 0 1 0

0 1 0 0

0 1 1 0

1 0 0 0

1 0 1 0

1 1 0 0

1 1 1 0

18.

LSB

19.

LSB

20.

CLK D Q

No X NC

Yes 0 0

Yes 1 1

SECTION 0.3: INSIDE THE COMPUTER

21. (a) 4

(b) 4

(c) 4

(d) 1 048 576, 2₂₀

(e) 1024K

(f) 1 073 741 824, 2₃₀

(g) 1 048 576 K

(h) 1024M

(i) 8388608, 8192K

22. Disk storage capacity / size of a page = $(2 \cdot 2_{30}) / (25 \cdot 80) = 1$ million pages

6

23. (a) 9FFFFh – 10000h = 8FFFFh = 589 824 bytes

(b) 576 kbytes

24. $2_{32} - 1 = 4\,294\,967\,295$

25. (a) FFh, 255

(b) FFFFh, 65535

(c) FFFF FFFFh, 4 294 967 295

(d) FFFF FFFF FFFF FFFFh, 18 446 744 073 709 551 615

26. (a) $2_{16} = 64K$

(b) $2_{24} = 16M$

(c) $2_{32} = 4096$ Mega, 4G

(d) $2_{48} = 256$ Tera, 262144 Giga, 268435456 Mega

27. Data bus is bidirectional, address bus is unidirectional (exit CPU).

28. PC (Program Counter)

29. ALU is responsible for all arithmetic and logic calculations in the CPU.

30. Address, control and data

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 7

CHAPTER 1: THE PIC MICROCONTROLLERS: HISTORY AND FEATURES

SECTION 1.1: MICROCONTROLLERS AND EMBEDDED PROCESSORS

1. False.

2. True.

3. True.

4. True.

5. CPU, RAM, ROM, EEPROM, I/O, Timer, Serial COM port, ADC.

6. RAM and ROM.

7. Keyboard, mouse, printer.

8. Computing power and compatibility with millions and millions of PCs.

9. PIC 16x – Microchip Technology, 8051 - Intel, AVR – Atmel, Z8 – Zilog,
68HC11 – Freescale Semiconductor (Motorola).

10. 8051.

11. Power consumption.

12. The ROM area is where the executable code is stored.

13. Very, in case there is a shortage by one supplier.
14. Suppliers other than the manufacturer of the chip.
15. B is absolutely wrong, 16 bit software can not run on a 8 bit system due to special instructions and registers. But A can be true (in the case of software compatibility).

SECTION 1.2: OVERVIEW OF THE PIC18 FAMILY

16. 32 Kbytes
17. 1536 bytes
18. 4 timers
19. 1536 bytes
20. PIC18C601, PIC18C801.
21. 36 pins
22. 1 serial port
23. Flash (see the letter 'F')
24. OTP (see the letter 'C')
25. Flash (see the letter 'F')
26. Flash (see the letter 'F')
27. (a) 16K ROM, 768 Bytes RAM
(b) 32K ROM, 1536 Bytes RAM
(c) 128K ROM, 3936 Bytes RAM
28. The OTP version of the PIC
29. The PIC18F2420 has 16Kbytes of Flash, no EEPROM, and 768 bytes of data RAM.
The
PIC18F2220 has 4Kbytes of Flash, 256 bytes of EEPROM, and 512 bytes of data RAM.
30. 256 bytes.

8

CHAPTER 2: PIC ARCHITECTURE & ASSEMBLY LANGUAGE PROGRAMMING

SECTION 2.1: THE WREG REGISTER IN PIC

1. 8
2. 8
3. 8
4. 0FFH
5. not necessary
6. MOVLW 15H ; WREG = 15H
ADDLW 13H ; WREG = 15H + 13H = 28H
7. In (a) and (d) the operand exceeds allowed range. The operand in (f) should start with 0.
The syntax of (g) is wrong.
8. (a), (c) and (d)
9. MOVLW 25H ; WREG = 25H
ADDLW 1FH ; WREG = 25H + 1FH = 44H
10. MOVLW 15H ; WREG = 15H
ADDLW 0EAH ; WREG = 15H + EAH = FFH
11. 255 or 0FFH
12. False. There is only one WREG in PIC.

SECTION 2.2: THE PIC FILE REGISTER

13. SRAM
14. True
15. True
16. False
17. False
18. Data RAM
19. (a) 32 bytes
(b) 80 bytes
(c) 4096 bytes
20. Each PIC has data RAM certainly, but one may not have EEPROM.
Data RAM is used to store temporary data and when power goes off, its information is lost. But, we use EEPROM to store nonvolatile data that must remain intact even when the power is turned off.
21. Yes. like PIC18F251 or PIC18F245
22. No
23. 256
24. 0
7Fh 80h
FFh
GP RAM
SFR
25. Maximum size of the file register / Maximum size of a bank = $4096/256 = 16$
26. 4096 bytes

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 9
SECTION 2.3: USING INSTRUCTIONS WITH THE DEFAULT ACCESS BANK

27. 0 – 7Fh (0 – 127)

28. MOVLW 30H

MOVWF 5H

MOVLW 97H

MOVWF 6H

29. MOVLW 55H

MOVWF 0H

MOVWF 1H

MOVWF 2H

MOVWF 3H

MOVWF 4H

MOVWF 5H

MOVWF 6H

MOVWF 7H

MOVWF 8H

30. MOVLW 5FH

MOVWF PORTB

31. True.

32. True.

33. 0 or W

34. 1 or F

35. (a)

MOVLW 11H

MOVWF 0H

MOVWF 1H

```

MOVWF 2H
MOVWF 3H
MOVWF 4H
MOVWF 5H
(b)
MOVLW 0x00
ADDWF 0H, W
ADDWF 1H, W
ADDWF 2H, W
ADDWF 3H, W
ADDWF 4H, W
ADDWF 5H, W
36. MOVLW 11H
MOVWF 0H
MOVWF 1H
MOVWF 2H
MOVWF 3H
MOVWF 4H
MOVWF 5H
MOVLW 0x00
ADDWF 0H, W
ADDWF 1H, W
ADDWF 2H, W
ADDWF 3H, W
ADDWF 4H, W
ADDWF 5H, F

```

10

```

37. (a)
MOVLW 15H
MOVWF 7H
(b)
MOVLW 0H
ADDWF 7H, W
ADDWF 7H, W
ADDWF 7H, W
ADDWF 7H, W
ADDWF 7H, W

```

```

38. (a)
MOVLW 15H
MOVWF 7H
(b)
MOVLW 0H
ADDWF 7H, F
ADDWF 7H, F
ADDWF 7H, F
ADDWF 7H, F
ADDWF 7H, F

```

39. MOVWF copies the contents of WREG to a location in file register. MOVF copies the contents of a location in file register to the itself (MOVF myfile, F) or WREG (MOVF myfile, W).

40. COMF 8H, W

41. True.

42. (a)

MOVF 8H, W
MOVWF PORTC

(b)

MOVFF 8H, PORTC

SECTION 2.4: PIC STATUS REGISTER

43. 8

44. D0 – D1

45. D3 – D4

46. When there is a carry out from D7 bit.

47. When there is a carry from D3 to D4.

48. $FFH + 1 = 11111111_2 + 1 = (1)00000000 \Rightarrow Z$ and C flags are both raised.

49. When the result is greater than 255 (FFh), the C flag will be raised:

(a) $54H + C4H = 118H \Rightarrow C = 1$

(b) $00H + FFH = FFH \Rightarrow C = 0$

(c) $FFH + 5H = 104H \Rightarrow C = 1$

50. MOVLW 0H

ADDLW 55H

ADDLW 55H

ADDLW 55H

ADDLW 55H

ADDLW 55H

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 11

SECTION 2.5: PIC DATA FORMAT AND DIRECTIVES

51. MYDAT_1 = 55H

MYDAT_2 = 62H

MYDAT_3 = 47H

MYDAT_4 = 50H

MYDAT_5 = C8H

MYDAT_6 = 41H

MYDAT_7 = AAH

MYDAT_8 = FFH

MYDAT_9 = 90H

MYDAT_10 = 7EH

MYDAT_11 = 0AH

MYDAT_12 = 0FH

52. DAT_1 = 22H (default radix is HEX)

DAT_2 = 56H

DAT_3 = 99H

DAT_4 = 20H

DAT_5 = F6H

DAT_6 = FBH

53.

R0 EQU 0H

R1 EQU 1H

R2 EQU 2H

R3 EQU 3H

R4 EQU 4H

R5 EQU 5H

(a)

```

MOVLW 11H
MOVWF R0
MOVWF R1
MOVWF R2
MOVWF R3
MOVWF R4
(b)MOVWF R5
MOVLW 0H
ADDWF R0, W
ADDWF R1, W
ADDWF R2, W
ADDWF R3, W
ADDWF R4, W
ADDWF R5, W

```

12

SECTION 2.6: INTRODUCTION TO PIC ASSEMBLY PROGRAMMING AND SECTION 2.7: ASSEMBLING AND LINKING A PIC PROGRAM

54. low - high

55. Assembly language, because it works directly with the internal hardware of the CPU and

uses them efficiently.

56. Assembler

57. True.

58. .err

59. False.

60. True. ORG is optional for MPLAB.

61. No.

62. Because they only tell the assembler what to do and do not generate any op-codes.

63. True.

64. False.

65. True.

66. hex

67. lst, hex, map, out, cod

SECTION 2.8: THE PROGRAM COUNTER AND PROGRAM ROM SPACE IN THE PIC

68. 000000H

69. When we power up the microcontroller, its Program Counter register has the default value 000000H. Therefore it fetches the content of location 000000H of the ROM and tries to execute it since it expects to see the first op-code of the program. If we place the first opcode at location 100H, the ROM burner places 0FFH into ROM locations 00H to 0FFH. Since the CPU wakes up at location 000000H, it executes the opcode 0FFFFH, which is a NOP instruction. This will delay execution of the users code until it reaches location 100H.

70. (a) – (g) 2 bytes

(h) 4 bytes

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 13

71. For ID number = 13590 we have:

```
ORG 0
```

```

;(a)
MOVLW 1H
MOVWF 0H
MOVLW 3H
MOVWF 1H
MOVLW 5H
MOVWF 2H
MOVLW 9H
MOVWF 3H
MOVLW 0H
MOVWF 4H
;(b)
MOVLW 0H
ADDWF 0H, W
ADDWF 1H, W
ADDWF 2H, W
ADDWF 3H, W
ADDWF 4H, W
MOVWF 6H
HERE GOTO HERE
END
LOC OBJECT CODE LINE SOURCE TEXT
000000 00001 ORG 0
00002 ;(a)
000000 0E01 00003 MOVLW 1H
000002 6E00 00004 MOVWF 0H
000004 0E03 00005 MOVLW 3H
000006 6E01 00006 MOVWF 1H
000008 0E05 00007 MOVLW 5H
00000A 6E02 00008 MOVWF 2H
00000C 0E09 00009 MOVLW 9H
00000E 6E03 00010 MOVWF 3H
000010 0E00 00011 MOVLW 0H
000012 6E04 00012 MOVWF 4H
00013 ;(b)
000014 0E00 00014 MOVLW 0H
000016 2400 00015 ADDWF 0H, W
000018 2401 00016 ADDWF 1H, W
00001A 2402 00017 ADDWF 2H, W
00001C 2403 00018 ADDWF 3H, W
00001E 2404 00019 ADDWF 4H, W
000020 6E06 00020 MOVWF 6H
000022 EF11 F000 00021 HERE GOTO HERE
00022 END
WORD HIGH LOW
ADDRESS BYTE BYTE
72.
000000h 0Eh 01h
000002h 6Eh 00h
000004h 0Eh 03h
000006h 6Eh 01h
000008h 0Eh 05h
00000Ah 6Eh 02h
00000Ch 0Eh 09h
00000Eh 6Eh 03h

```

000010h 0Eh 00h
000012h 6Eh 04h
000014h 0Eh 00h
000016h 24h 00h
000018h 24h 01h
00001Ah 24h 02h
00001Ch 24h 03h
00001Eh 24h 04h
000020h 6Eh 06h
000022h EFh 11h
000024h F0h 00h

14

73. (a) Size of ROM = $48 \times 1024 = 49152$ bytes = C000h $\Rightarrow$ Last location = C000h - 1 = BFFFh
(b) Size of ROM = $96 \times 1024 = 98304$ bytes = 18000h $\Rightarrow$ Last location = 18000h - 1 = 17FFFh
(c) Size of ROM = $64 \times 1024 = 65536$ bytes = 10000h $\Rightarrow$ Last location = 10000h - 1 = FFFFh
(d) Size of ROM = $16 \times 1024 = 16384$ bytes = 4000h $\Rightarrow$ Last location = 4000h - 1 = 3FFFh
(e) Size of ROM = $128 \times 1024 = 131072$ bytes = 20000h $\Rightarrow$ Last location = 20000h - 1 = 1FFFFh
74. Since the program counter of PIC18 has 21 bits, it takes from 000000h to 1FFFFFFh
75. Size of ROM = Last location address + 1 = 7FFFh + 1 = 8000h = 32768 bytes = 32KB
76. Size of ROM = Last location address + 1 = 3FFh + 1 = 400h = 1024 bytes = 1KB
77. (a) Size of ROM = Last location address + 1 = 1FFFh + 1 = 2000h = 8192 bytes = 8KB
(b) Size of ROM = Last location address + 1 = 3FFFh + 1 = 4000h = 16384 bytes = 16KB
(c) Size of ROM = Last location address + 1 = 5FFFh + 1 = 6000h = 24576 bytes = 24KB
(d) Size of ROM = Last location address + 1 = BFFFh + 1 = C000h = 49152 bytes = 48KB
(e) Size of ROM = Last location address + 1 = FFFFh + 1 = 10000h = 65536 bytes = 64KB
(f) Size of ROM = Last location address + 1 = 1FFFFh + 1 = 20000h = 131072 bytes = 128KB
(g) Size of ROM = Last location address + 1 = 2FFFh + 1 = 3000h = 196608 bytes = 192KB
(h) Size of ROM = Last location address + 1 = 3FFFh + 1 = 4000h = 262144 bytes = 256KB
78. (a) Size of ROM = 4FFFFh + 1 = 50000h = 327680 bytes = 320KB
(b) Size of ROM = 3FFFFh + 1 = 40000h = 262144 bytes = 256KB
(c) Size of ROM = 5FFFFh + 1 = 60000h = 393216 bytes = 384KB
(d) Size of ROM = 7FFFFh + 1 = 80000h = 524288 bytes = 512KB
(e) Size of ROM = BFFFFh + 1 = C0000h = 786432 bytes = 768KB
(f) Size of ROM = FFFFFh + 1 = 100000h = 1048576 bytes = 1024KB
(g) Size of ROM = 17FFFFh + 1 = 180000h = 1572864 bytes = 1536KB
(h) Size of ROM = 1FFFFFFh + 1 = 200000h = 2097152 bytes = 2048KB

79. 16 bits

80. 16 bits

81.

0001
0003
0005
0000
0002
0004
1FFD
1FFF
1FFC

1FFE

High Byte Low Byte

82. 8KB

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 15

83.

0001

0003

0005

0000

0002

0004

7FFD

7FFF

High Byte Low Byte

7FFC

7FFE

84. 32KB

85. In Harvard architecture, there are 4 sets of buses: (1) a set of data buses for carrying data

into and out of the CPU, (2) a set of address buses for accessing (addressing) the data, (3) a set of data buses for carrying code into the CPU, (4) an address bus for accessing (addressing) the code. With the use of four buses and separate accessing systems to data and code, none of them can get in the other's way and slow down the system.

86. Large number of CPU pins needed for duplicated buses – Large numbers of wire traces

needed for the system wiring.

87. Because MOVLW is a 2-byte instruction. The first 8-bit is the main op-code and the second 8-bit is used for the literal value. A binary number with 8 bits can store at most 255 (11111111B – FFh).

88. Because ADDLW is a 2-byte instruction. The first 8-bit is the main op-code and the second 8-bit is used for the literal value. A binary number with 8 bits can store at most 255 (11111111B – FFh).

89. It is a 2-byte instruction. The first 8-bit is the op-code and the second 8-bit determines a

location in a bank of the file register (Access bank or another bank which is determined by the LSB bit of the first 8-bit). Each bank has 256 bytes and can be covered by 8 bits for address.

90. It is a 4-byte instruction. The first 16-bit is the op-code and the source address and the second 16-bit is op-code and the destination address. In each 16-bit, 12 bits are set aside to determine the address which can cover the entire 4KB space of data RAM.

91. Because the data bus between the CPU and ROM of PIC18 microcontrollers is 16 bits wide. Whenever CPU fetches the data from ROM, it receives 2 bytes. Therefore data is always fetched starting from even addresses and because of this, program counter always holds even values and its LSB is 0.

92. Because the LSB of program counter is always 0. So it holds only even values (see problem 91).

93. Because there are only 2-byte and 4-byte instructions in PIC18 microcontrollers and all

instructions are stored in ROM starting from even addresses. If program counter could

get odd values, it would land at an odd address (in the middle of an instruction).

94. It is a 4-byte instruction that 20 bits out of these 32 bits are set aside to determine an address. As mentioned above, the LSB of the program counter is always zero to assure fetching op-codes from even addresses. 20 bits as well as this bit, form 21 bits that can cover 2MB of ROM.

16

SECTION 2.9: RISC ARCHITECTURE IN THE PIC

95. RISC stands for "Reduced Instruction Set Computer". CISC stands for "Complex (or Complete) Instruction Set Computer".

96. CISC

97. RISC

98. RISC

99. CISC

100. False

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 17

CHAPTER 3: BRANCH, CALL AND TIME DELAY LOOP

SECTION 3.1: BRANCH INSTRUCTIONS AND LOOPING

1. 255

2. the instruction following the branch instruction

3. Program Counter (the low byte)

4. Branch, 2

5. 4

6. BRA takes 2 bytes and GOTO take 4 bytes. So using BRA saves ROM space

7. False. All conditional branches are short jumps that the target can be within 128 bytes of

the jump instruction.

8. False.

9. All are of the are 2 bytes except (c) which is 4 bytes.

10. It is a 2-byte instruction; The first 5 bits are the op-code and 11 bits are set aside for relative addressing of the target location. With 11 bits, the relative address is within -1024 to +1023y So the jump can be taken within a space of 2Kbytes (1023 bytes forward and 1024 bytes backward).

11. True

12.

R4 EQU 4

R5 EQU 5

R6 EQU 6

MOVLW D'10'

MOVWF R6

BACK MOVLW D'100'

MOVWF R5

AGAIN MOVLW D'100'

MOVWF R4

HERE NOP

NOP

DECF R4

BNZ HERE

DECF R5

BNZ AGAIN

```

DECF R6
BNZ BACK
R5 EQU 5
R6 EQU 6
MOVLW D'10'
MOVWF R5
BACK MOVLW D'100'
MOVWF R6
HERE NOP
NOP
DECF R6
BNZ HERE
DECF R5
BNZ BACK

```

13.

18

14. The BACK loop is performed 200 times. The HERE loop is performed 100 times and

because it is located in the BACK loop, it is repeated 200 times. So the instructions in the HERE loop are performed $200 \times 100 = 20,000$ times.

15. Negative.

16. Positive.

SECTION 3.2: CALL INSTRUCTIONS AND STACK

17. 4

18. 2

19. False.

20. True

21. 1

22. 1

23. 01

24. When the subroutine is called, the CPU saves the address of the next instruction on to the

top of the stack. At the end of the subroutine when the instruction RETURN is executed, the CPU takes the address from the top of stack and loads the PC register with it and continues to execute at the instruction after the CALL.

25. 31 locations of 21 bits each.

26. The address of the instruction after the CALL is pushed to the stack and the SP is decremented by 1.

SECTION 3.3: PIC18 TIME DELAY AND INSTRUCTION PIPELINE

27. Instruction frequency = $1 / 1.25\mu\text{s} = 800\text{KHz}$; Oscillator frequency = $800\text{KHz} \times 4 = 3.2\text{MHz}$

28. $20\text{MHz} / 4 = 5\text{MHz}$; Instruction Cycle = $1 / 5\text{MHz} = 200\text{ns}$

29. $10\text{MHz} / 4 = 2.5\text{MHz}$; Instruction Cycle = $1 / 2.5\text{MHz} = 400\text{ns}$

30. $16\text{MHz} / 4 = 4\text{MHz}$; Instruction Cycle = $1 / 4\text{MHz} = 250\text{ns}$

31. True

In the next 4 problems, we dispense with the overhead associated with the outer loops.

Note that

the BNZ instruction takes 2 instruction cycles when it takes jump and 1 instruction cycle when it

falls through.

32. Instruction cycle = $1\mu\text{s}$; HERE loop lasts $(1+1+2)*100 - 1 = 399$ instruction cycles.

Overall delay = $[399*200 + (1+1+1+2)*200] * 1\mu\text{s} = 80.8\text{ ms}$

33. Instruction cycle = 250 ns ; HERE loop lasts $(1+1+1+2)*100 - 1 = 499$ instruction cycles.

Overall delay = $[499*200 + (1+1+1+2)*200] * 250\text{ ns} = 25.2\text{ ms}$

34. Instruction cycle = $1\mu\text{s}$; HERE loop lasts $(1+1+2)*250 - 1 = 999$ instruction cycles.

Overall delay = $[999*200 + (1+1+1+2)*200] * 1\mu\text{s} = 200.8\text{ ms}$

35. Instruction cycle = 400 ns ; HERE loop lasts $(1+2)*100 - 1 = 299$ instruction cycles.

Overall delay = $[299*200 + (1+1+1+1+1+2)*200] * 400\text{ ns} = 24.56\text{ ms}$. Note that the 3 NOPs are outside of the inner loop.

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 19

CHAPTER 4: PIC I/O PORT PROGRAMMING

SECTION 4.1: I/O PORT PROGRAMMING IN PIC18

1. 40

2. 4 pins. Pins 11 and 32 assigned to Vdd and pins 12 and 31 are assigned to Gnd.

3. 34

4. 7 Pins, 2-7 and 14.

5. 8 Pins, 33-40.

6. 8 Pins, 15-18 and 23-26.

7. 8 Pins, 19-22 and 27-30.

8. input

9. TRISx

10. Both are SFR registers associated to I/O ports. PORTx registers are used to access the I/O pins and TRISx registers are used to configure I/O ports as input or output.

11.

```
SETF TRISC ;Define PORTC as input
CLRF TRISB ;Define PORTB as output
CLRF TRISD ;Define PORTD as output
MOVF PORTC, W
NOP
MOVWF PORTB
MOVWF PORTD
```

12.

```
SETF TRISD ;Define PORTD as input
CLRF TRISB ;Define PORTB as output
CLRF TRISC ;Define PORTC as output
MOVFF PORTD, PORTB
MOVFF PORTD, PORTC
```

13. 26 and 25 respectively

14. F80h, F81h and F82h for PORTx and F92h, F93h and F94h for TRISx.

15. (a) (b)

```
CLRF TRISB
CLRF TRISC
BACK MOVLW 55H
MOVWF PORTB
MOVWF PORTC
CALL DELAY
MOVLW AAH
MOVWF PORTB
```

```

MOVWF PORTC
CALL DELAY
GOTO BACK
CLRF TRISB
CLRF TRISC
MOVLW 55H
MOVWF PORTB
MOVWF PORTC
BACK CALL DELAY
COMF PORTB
COMF PORTC
BRA BACK

```

20

SECTION 4.2: I/O BIT MANIPULATION PROGRAMMING

16. All SFR registers of the PIC18 (including I/O ports) are bit addressable.

17. The advantage of the bit addressing is that it allows each bit to be modified without affecting the other bits.

18. PORTB,RB2

19. Yes (since COMF is a read-modify-write instruction)

20.

```

BCF TRISB, 2 ;Define PB2 as output
BCF TRISB, 5 ;Define PB5 as output
BACK BTG PORTB, 2
BTG PORTB, 5
CALL DELAY
BRA BACK

```

21.

```

BCF TRISD, 3 ;Define PD3 as output
BCF TRISD, 7 ;Define PD7 as output
BCF TRISC, 5 ;Define PC5 as output
BACK BTG PORTD, 3
BTG PORTD, 7
BTG PORTC, 5
CALL DELAY
BRA BACK

```

22.

```

BSF TRISC, 3 ;Define PC3 as input
CLRF TRISD ;Define PD as output
MOVLW 0x55
BACK BTFSS PORTC, 3
BRA BACK
MOVWF PORTD

```

23.

```

BSF TRISB, 7 ;Define PB7 as input
CLRF TRISC ;Define PC as output
OVER BTFSC PORTB, 7
BRA OVER
BACK MOVLW 0x55
MOVWF PORTC
CALL DELAY
MOVLW 0xAA
MOVWF PORTC
CALL DELAY
BRA BACK

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 21

24.

```
BSF TRISE, 0 ;Define PE0 as input
CLRF TRISB ;Define PB as output
CLRF TRISC ;Define PC as output
TEST BTFSC PORTE, 0
BRA BIT_H
MOVLW 0x66
MOVWF PORTC
BRA TEST
BIT_H MOVLW 0x99
MOVWF PORTB
BRA TEST
```

25.

```
BSF TRISC, 3 ;Define PC3 as input
BCF TRISC, 4 ;Define PC4 as output
BACK BTFSS PORTB, 3
BRA BIT_L
BSF PORTB, 4
BRA BACK
BIT_L BCF PORTB, 4
BRA BACK
BSF TRISB, 5 ;Define PB5 as input
BCF TRISB, 3 ;Define PB3 as output
BACK BTFSS PORTB, 5
BRA BACK
BCF PORTB, 3
BSF PORTB, 3
BCF PORTB, 3
```

26.

27. Bit number 4 (D4 of D0 – D7)

28.

```
BSF TRISD, 6 ;Define PD6 as input
BSF TRISD, 7 ;Define PD7 as input
BCF TRISC, 0 ;Define PC0 as output
BCF TRISC, 7 ;Define PC7 as output
BACK BTFSS PORTD, 7
BRA BIT7_L
BSF PORTC, 0
BRA NEXT
BIT7_L BCF PORTC, 0
NEXT BTFSS PORTD, 6
BRA BIT6_L
BSF PORTC, 7
BRA BACK
BIT6_L BCF PORTC, 7
BRA BACK
```

22

NOTE: All the codes above, are not complete program. To form a complete program, you should observe the standard structure of the PIC18(F458) programs which comes below. If you want to perform it on a real PIC cheap, maybe you should use **GOTO \$** in some parts of programs to halt it.

```

list P = PIC18F458
#include P18F458.INC
ORG 0
; Place your code here
-----
HERE GOTO HERE ;Where you want to halt the program
END

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 23
CHAPTER 5: ARITHMETIC, LOGIC INSTRUCTIONS ,AND PROGRAMS
SECTION 5.1: ARITHMETIC INSTRUCTIONS

1. All the calculations are done in hexadecimal system.

a) 3 F
+ 4 5
8 4 C = 0, Z = 0, DC = 1

b) 9 9
+ 5 8
F 1 C = 0, Z = 0, DC = 1

c) 1
+ F F
+ 0 0
(1) 0 0 C = 1, Z = 1, DC = 1

d) F F
+ 0 1
(1) 0 0 C = 1, Z = 1, DC = 1

e) 1
+ F E
+ 0 0
F F C = 0, Z = 0, DC = 0

f) 0
F F
+ 0 0
F F C = 0, Z = 0, DC = 0

2. For the ID number = 4305:

```

MOVLW D'4'
ADDLW D'3'
DAW
ADDLW D'0'
DAW
ADDLW D'5'
DAW
MOVWF 0x20

```

24

3.

4.

```

MYREG EQU 0x20
MOVLW 0x25
ADDLW 0x59
DAW
ADDLW 0x65
DAW

```

```

MOVWF MYREG
MYREG EQU 0x20
MOVLW 0x25
ADDLW 0x59
ADDLW 0x65
MOVWF MYREG

```

5. a)

```

MOVLW 0x25
MOVWF 0x20
MOVWF 0x21
MOVWF 0x22
MOVWF 0x23

```

b)

```

MOVF 0x20, W
ADDWF 0x21, W
ADDWF 0x22, W
ADDWF 0x23, W
MOVWF 0x60

```

6. a) $23H - 12H = 23H + 2's(12H) = 23H + EEH = (1) 11H \rightarrow +11H$

b) $43H - 53H = 43H + 2's(53H) = 43H + ADH = (0) F0H \rightarrow -10H$

c) $99H - 99H = 99H + 2's(99H) = 99H + 67H = (1) 00H \rightarrow 0$

7. a) MOVLW 23H b) MOVLW 43H c) MOVLW D'99'

SUBLW 12H SUBLW 53H SUBLW D'99'

8. True

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 25

9. BYTE_L EQU 0x40

BYTE_H EQU 0x41

BYTE_U EQU 0x42

MOVLW 0x9A

MOVWF BYTE_L

MOVLW 0x7F

MOVWF BYTE_H

MOVLW 0

MOVWF BYTE_U

MOVLW 0x48

ADDWF BYTE_L, F

MOVLW 0xBC

ADDWFC BYTE_H, F

MOVLW 0x00

ADDWFC BYTE_U, F

10.

BYTE_L EQU 0x40

BYTE_H EQU 0x41

MOVLW 0x48

MOVWF BYTE_L

MOVLW 0xBC

MOVWF BYTE_H

MOVLW 0x9A

SUBWF BYTE_L, F

MOVLW 0x7F

SUBWFB BYTE_H, F

26

11.

BYTE_L EQU 0x40

```

BYTE_H EQU 0x41
BYTE_U EQU 0x42
MOVLW 0x95
MOVWF BYTE_L
MOVLW 0x77
MOVWF BYTE_H
MOVLW 0
MOVWF BYTE_U
MOVLW 0x48
ADDWF BYTE_L, W
DAW
MOVWF BYTE_L
MOVLW 0x95
ADDWFC BYTE_H, W
DAW
MOVWF BYTE_H
MOVLW 0x0
ADDWFC BYTE_U, W
DAW
MOVWF BYTE_U

```

12. MOVLW D'77'

MULLW D'34'

; The result will be in double register PRODH-PRODL

13.

```

NUM EQU 0x19
MYQ EQU 0x20
REM EQU 0x21
DENUM EQU D'3'
CLRF MYQ
MOVLW D'77'
MOVWF NUM
MOVLW DENUM
AGAIN SUBWF NUM, F
INCF MYQ, F
BNN AGAIN
DECF MYQ, F
ADDWF NUM, F
MOVFF NUM, REM

```

14. False

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 27

15. PRODH-PRODL

SECTION 5.2: SIGNED NUMBER CONCEPTS AND ARITHMETIC OPERATIONS

16. a) 1110 1001 b) 0000 1100 c) 1110 0100 d) 0110 1111

e) 1000 0000 f) 0111 1111

17. unsigned

18. a) MOVLW +D'15' 0000 1111 + 1111 0100 = (1)0000 0011

ADDLW -D'12' OV = 0

b) MOVLW -D'123' 1000 0101 + 1000 0001 = (1)0000 0110

ADDLW -D'127' OV = 1

c) MOVLW +25H 0010 0101 + 0011 0100 = (0)0101 1001

ADDLW +34H OV = 0

d) MOVLW -D'127' 1000 0001 + 0111 1111 = (1)0000 0000

ADDLW +D'127' OV = 0

19. C flag is raised when there is a carry out of D7 of the result, but OV flag is raised when

there is a carry from D6 to D7 and no carry out of D7 or when there is no carry from D6 to D7 and there is a carry out of D7 of the result. C flag is used to indicate overflow in unsigned arithmetic operations while OV flag is involved in signed operations.

20. When there is a carry from D6 to D7 of result, but there is no carry out of D7 (C = 0) OR

when there is no carry from D6 to D7 of result, but there is a carry out of D7 (C=1)

21. STATUS

22. BOV and BNOV instructions - BC and BNC instructions

SECTION 5.3: LOGIC AND COMPARE INSTRUCTIONS

23. All the results are stored in WREG register.

a) 0x40 b) 0xF0 c) 0x86 d) 0x90 e) 0x60 f) 0xF0

g) 0xF0 h) 0xF9 i) 0x1E j) 0x5A

24. a) 0x64 b) 0x7B c) 0x3F d) 0x58 e) 0xD7 f) 0x04

g) 0x37

25. True

28

26. "CPFSGT FileReg" subtracts WREG from FileReg without changing them. If the result is positive, it means FileReg > WREG and the next instructions is ignored (skipped over). Otherwise the next instruction will be performed.

27. No

28. a) 85h < 90h → No skip b) 85h > 70h → Skip

c) Skip d) 85h > 5Dh → No skip

29. a) 86h b) 85h d) 85h e) 86h

SECTION 5.4: ROTATE INSTRUCTION AND DATA SERIALIZATION

30. a) MOVLW 0x56 ; WREG = 0x56

MOVWF MYREG ; WREG = 0x56 , MYREG = 0x56 = 0101 0110

SWAPF MYREG,F ; WREG = 0x56 , MYREG = 0x65 = 0110 0101

RRCF MYREG,F ; WREG = 0x56 , MYREG = 0x32 = 0011 0010 (C = 1)

RRCF MYREG,F ; WREG = 0x56 , MYREG = 0x99 = 1001 1001 (C = 0)

b) MOVLW 0x39 ; WREG = 0x39

BCF STATUS, C ; WREG = 0x39 , C = 0

MOVWF MYREG,F ; WREG = 0x39 , MYREG = 0x39 = 0011 1001

RLCF MYREG,F ; WREG = 0x39 , MYREG = 0x72 = 0111 0010 (C = 0)

RLCF MYREG,F ; WREG = 0x39 , MYREG = 0xE4 = 1110 0100 (C = 0)

c) BCF STATUS, C ; C = 0

MOVLW 0x4D ; WREG = 0x4D

MOVWF MYREG ; WREG = 0x4D , MYREG = 0x4D = 0100 1101

SWAPF MYREG,F ; WREG = 0x4D , MYREG = 0xD4 = 1101 0100

RRCF MYREG,F ; WREG = 0x4D , MYREG = 0x6A = 0110 1010 (C = 0)

RRCF MYREG,F ; WREG = 0x4D , MYREG = 0x35 = 0011 0101 (C = 0)

RRCF MYREG,F ; WREG = 0x4D , MYREG = 0x1A = 0001 1010 (C = 1)

d) BCF STATUS, C ; C = 0

MOVLW 0x7A ; WREG = 0x7A

```
MOVWF MYREG ; WREG = 0x7A , MYREG = 0x7A = 0111 1010
SWAPF MYREG,F ; WREG = 0x7A , MYREG = 0xA7 = 1010 0111
RLCF MYREG,F ; WREG = 0x7A , MYREG = 0x4E = 0100 1110 (C = 1)
RLCF MYREG,F ; WREG = 0x7A , MYREG = 0x9D = 1001 1101 (C = 0)
```

31. a) RRNCF FileReg, F b) RLNCF FileReg, F

RRNCF FileReg, F RLNCF FileReg, F

RRNCF FileReg, F RLNCF FileReg, F

RRNCF FileReg, F RLNCF FileReg, F

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 29

32.

33.

```
MYREG EQU 0x20 ;Contains data
```

```
COUNTER EQU 0x21
```

```
RESULT EQU 0x22
```

```
CLRF RESULT
```

```
MOVLW 8
```

```
MOVWF COUNTER
```

```
AGAIN RRCF MYREG, F
```

```
BC NEXT
```

```
INCF RESULT, F
```

```
NEXT DECF COUNTER, F
```

```
BNZ AGAIN
```

```
MYREG EQU 0x20
```

```
COUNTER EQU 0x21
```

```
POSITION EQU 0x22
```

```
CLRF POSITION
```

```
MOVLW 8
```

```
MOVWF COUNTER
```

```
MOVLW 68H
```

```
MOVWF MYREG
```

```
AGAIN RRCF MYREG, F
```

```
BC OVER
```

```
INCF POSITION, F
```

```
DECF COUNTER, F
```

```
BNZ AGAIN
```

```
OVER
```

```
;POSITION = 3 FOR 68H (0110 1000)
```

If POSITION is 8 at the location OVER, it means no high bit is found in MYREG.

34.

```
MYREG EQU 0x20
```

```
COUNTER EQU 0x21
```

```
POSITION EQU 0x22
```

```
MOVLW 7
```

```
MOVWF POSITION
```

```
MOVLW 8
```

```
MOVWF COUNTER
```

```
MOVLW 68H
```

```
MOVWF MYREG
```

```
AGAIN RLCF MYREG, F
```

```
BC OVER
```

```
DECF POSITION, F
```

```
DECF COUNTER, F
```

```
BNZ AGAIN
```

```
OVER
```

;POSITION = 6 FOR 68H (0110 1000)

If POSITION is 255 at the location OVER, it means no high bit is found in MYREG.

30

35. Consider value CCh (1100 1100). The sequential rotation is shown below:

right rotation: **1100 1100** → 0110 0110 → 0011 0011 → 1001 1001 → **1100 1100** → ...

left rotation : **1100 1100** → 1001 1001 → 0011 0011 → 0110 0110 → **1100 1100** → ...

As you see, after four rotations the value comes back to its original value. Furthermore, 4 lower bits and 4 upper bits generate stepper motor patterns independently.

MYREG EQU 0x20

MOVLW 0xCC

MOVWF MYREG

AGAIN RRNCF MYREG, F (or RLNCF MYREG, F)

BRA AGAIN

SECTION 5.5: BCD AND ASCII CONVERSION

36. In the following program we assume Little Endian storing scheme.

ASCII1 EQU 0x40

ASCII2 EQU 0x41

ASCII3 EQU 0x42

ASCII4 EQU 0x43

MOVLW MYBCD_1 ; WREG = 0x76

ANDLW 0x0F ; WREG = 0x06

IORLW 0x30 ; WREG = 0x36

MOVWF ASCII1 ; ASCII1 = 0x36 = '6'

MOVLW MYBCD_1 ; WREG = 0x76

ANDLW 0xF0 ; WREG = 0x70

MOVWF ASCII2 ; ASCII2 = 0x70

SWAPF ASCII2, F ; ASCII2 = 0x07

MOVLW 0x30 ; WREG = 0x30

IORWF ASCII2, F ; ASCII2 = 0x37 = '7'

MOVLW MYBCD_2 ; WREG = 0x87

ANDLW 0x0F ; WREG = 0x07

IORLW 0x30 ; WREG = 0x37

MOVWF ASCII3 ; ASCII3 = 0x37 = '7'

MOVLW MYBCD_2 ; WREG = 0x87

ANDLW 0xF0 ; WREG = 0x80

MOVWF ASCII4 ; ASCII4 = 0x80

SWAPF ASCII4, F ; ASCII4 = 0x08

MOVLW 0x30 ; WREG = 0x30

IORWF ASCII4, F ; ASCII4 = 0x38 = '8'

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 31

37.

BCD1 EQU 0x60

BCD2 EQU 0x61

MOVLW MYASC_1 ; WREG = '8' = 0x38

ANDLW 0x0F ; WREG = 0x08

MOVWF BCD1 ; BCD1 = 0x08

SWAPF BCD1, F ; BCD1 = 0x80

MOVLW MYASC_2 ; WREG = '7' = 0x37

ANDLW 0x0F ; WREG = 0x07

IORWF BCD1, F ; BCD1 = 0x87

MOVLW MYASC_3 ; WREG = '9' = 0x39

ANDLW 0x0F ; WREG = 0x09

MOVWF BCD2 ; BCD2 = 0x09

```

SWAPF BCD2, F ; BCD2 = 0x90
MOVLW MYASC_4 ; WREG = '2' = 0x32
ANDLW 0x0F ; WREG = 0x02
IORWF BCD2, F ; BCD2 = 0x92

```

32

CHAPTER 6: BANK SWITCHING, TABLE PROCESSING, MACROS AND MODULES

SECTION 6.1: IMMEDIATE AND DIRECT ADDRESSING MODES

1. b. MOVLW takes only one operand which is an immediate value.
2. a) Direct b) Immediate c) Direct d) Immediate e) Direct f) Direct
3. According to Figure 2-4:
 - a) F81h b) FE8h c) F82h d) F83h e) FF9h f) FFAh g) FFBh h) F94h
 - i) F93h j) FD8h k) FE9h
4. Bank 15 (F)
5. Direct
6. Copies the value F0h to WREG register.
7. Copies the contents of WREG register to PORTC.
8. Copies the contents of PORTC to WREG register.
9. valid
10. 00 - 7F
11. F80h - FFFh
12. a) 00 - 7F b) 80 - FF There is no gap between them.

13.

```

MOVLW 6
ADDLW 9
ADDLW 2
ADDLW 5
ADDLW 7
MOVWF 0x20

```

SECTION 6.2: REGISTER INDIRECT ADDRESSING MODE

14. FSR0 (LFSR 0, RAM ADDRESS), FSR1 (LFSR 1, RAM ADDRESS), FSR2 (LFSR 2, RAM ADDRESS)

15.

```

RAM_ADDR EQU 50H
COUNT_REG EQU 0x20
COUNT_VAL EQU 1FH
MOVLW COUNT_VAL
MOVWF COUNT_REG
LFSR 0, RAM_ADDR
MOVLW 0xFF
AGAIN MOVWF INDF0
INCF FSR0L, F
DECF COUNT_REG, F
BNZ AGAIN

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 33

16.

```

COUNT_VAL EQU D'10'
COUNT_REG EQU 0x20
SRC_ADDR EQU 40H
DEST_ADDR EQU 70H
ORG 0

```

```

MOVLW COUNT_VAL
MOVWF COUNT_REG
LFSR 0, SRC_ADDR
LFSR 1, DEST_ADDR
NEXT MOVF INDF0, W
MOVWF INDF1
INCF FSR0L, F
INCF FSR1L, F
DECF COUNT_REG, F
BNZ NEXT
BRA $
END

```

17. 12 bits

18. FSR0: FSR0L, FSR0H, FSR1: FSR1L, FSR1H

19.

```

COUNT_VAL EQU 7FH
COUNT_REG EQU 0x20
ORG 0
MOVLW COUNT_VAL
MOVWF COUNT_REG
LFSR 2, 0x00
AGAIN CLRF POSTINC2, F
DECF COUNT_REG, F
BNZ AGAIN
BRA $
END

```

34

20.

21. INDFx keeps content of the RAM location with address FSRx.

22. 4KB

SECTION 6.3: LOOK-UP TABLE AND TABLE PROCESSING

23.

NOTE: 1- When you see the contents of these cells of memory in MPLAB, you will see that the contents of each two sequent bytes are displayed in reverse order (high byte is shown first). This is done to ease dealing with little endian storing scheme.

2- Every new DB directive, will align consequent bytes on the next even address (notice 00 in location 205)

24.

ROM Location (hex) 200 201 202 203 204 205 206 207 208 209

Contents (hex) 45 61 72 74 68 00 39 38 37 2D

ROM Location (hex) 20A 20B 20C 20E 20F 210 211 212 208 209

Contents (hex) 36 35 47 41 42 45 48 20 39 38

ROM Location (hex) 340 341 342 343 344 345

Contents (hex) 22 56 99 20 F6 FB

```

COUNT_VAL EQU 0FH
COUNT_REG EQU 0x20
ORG 0
MOVLW COUNT_VAL
MOVWF COUNT_REG
LFSR 0, 0x50
NEXT COMF POSTINC0, F
DECF COUNT_REG, F

```

```

BNZ NEXT
BRA $
END

```

25. TBLPTRL, TBLPTRH and TBLPTRU. They are loaded with these instructions:

MOVLW proper portion of a ROM address

MOVWF TBLPTRx

which x is L (for loading bits 0-7 of pointer), H (for loading bits 8-15 of pointer) or U (for loading bits 16-20 of pointer. Bits 21-23 are set to zero).

26. TABLAT keeps content of the ROM location with address TBLPTR.

27. 21 bits. 2 MB

28. TBLPTRL, TBLPTRH and TBLPTRU

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 35

29. RAM_ADDR EQU 50H

```

ORG 0000

```

```

MOVLW 0x00

```

```

MOVWF TBLPTRL

```

```

MOVLW 0x6

```

```

MOVWF TBLPTRH

```

```

LFSR 0, RAM_ADDR

```

```

NEXT TBLRD*+

```

```

MOVF TABLAT, W

```

```

BZ EXIT

```

```

MOVWF POSTINC0

```

```

BRA NEXT

```

```

EXIT BRA EXIT

```

```

;-----MESSAGE

```

```

ORG 0x600

```

```

DB "1-800-999-9999", 0

```

```

END

```

30. In the following program we assume to get "x" from PORTB and send "y" to PORTC.

```

ORG 0000

```

```

SETF TRISB

```

```

CLRF TRISC

```

```

NEXT MOVF PORTB, W

```

```

ANDLW 0x0F

```

```

CALL Y_TABLE

```

```

MOVWF PORTC

```

```

BRA NEXT

```

```

;----- Y_TABLE SUBROUTINE

```

```

Y_TABLE

```

```

MULLW 0x2

```

```

MOVF PRODL, W

```

```

ADDWF PCL, F

```

```

DT D'5', D'8', D'13', D'20', D'29', D'40'

```

```

DT D'53', D'68', D'85', D'104'

```

```

END

```

We can replace two last lines of the Y_TABLE with:

```

retlw D'5'

```

```

retlw D'8'

```

```

...

```

```

retlw D'85'

```

```

retlw D'104'

```

36

31. We solve this problem by placing look-up table in data RAM. We assume that contents of

RAM locations starting at address 20h are: 5-25-45-65-85-105-125-145-165-185. Input and output ports are PORTB and PORTC respectively.

```
ORG 0000
SETF TRISB
CLRF TRISC
LFSR 0, 0x20
NEXT MOVF PORTB, W
ANDLW 0x0F
MOVFF PLUSW0, PORTC
BRA NEXT
END
```

32.

```
RAM_ADDR EQU 40H
ORG 0000
MOVLW 0x00
MOVWF TBLPTRL
MOVLW 0x7
MOVWF TBLPTRH
LFSR 0, RAM_ADDR
NEXT TBLRD*+
MOVF TABLAT, W
BZ EXIT
MOVWF POSTINC0
BRA NEXT
EXIT BRA EXIT
;-----MESSAGE
ORG 0x700
DB "The earth is but one country",0
END
```

33. True

34. True

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 37

35.

```
ORG 0000
SETF TRISB
CLRF TRISC
NEXT MOVF PORTB, W
ANDLW 0x0F
CALL ASCII_TABLE
MOVWF PORTC
BRA NEXT
;----- TABLE PROCESSING
ASCII_TABLE
MULLW 0x2
MOVFF PRODL, WREG
ADDWF PCL, F
DT "0123456789ABCDEF"
END
```

SECTION 6.4: BIT-ADDRESSABILITY OF DATA RAM

36.

```
COUNT_VAL EQU 0xFF
```

```

COUNT_REG EQU 0x20
ORG 0
BCF TRISB,5
AGAIN BSF PORTB,5
CALL DELAY
CALL DELAY
CALL DELAY
BCF PORTB,5
CALL DELAY
BRA AGAIN
;----- DELAY SUBROUTIN
DELAY
MOVLW COUNT_VAL
MOVWF COUNT_REG
LOOP NOP
NOP
DECF COUNT_REG,F
BNZ LOOP
RETURN
END

```

38

37.

```

COUNT_VAL EQU 0xFF
COUNT_REG EQU 0x20
ORG 0
BCF TRISC,7
AGAIN BSF PORTC,7
CALL DELAY
CALL DELAY
CALL DELAY
CALL DELAY
BCF PORTC,7
CALL DELAY
BRA AGAIN
;----- DELAY SUBROUTINE
DELAY
MOVLW COUNT_VAL
MOVWF COUNT_REG
LOOP NOP
NOP
DECF COUNT_REG,F
BNZ LOOP
RETURN
END

```

38.

```

COUNT_VAL EQU 0xFF
COUNT_REG EQU 0x20
ORG 0
BSF TRISB,4
BCF TRISB,7
HERE BTFSS PORTB,4
BRA HERE
AGAIN BTG PORTB,7
CALL DELAY
BRA AGAIN
;----- DELAY SUBROUTIN

```

```

DELAY
MOVLW COUNT_VAL
MOVWF COUNT_REG
LOOP NOP
NOP
DECF COUNT_REG, F
BNZ LOOP
RETURN
END

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 39

39.

```

COUNT EQU 0x20
ORG 0
BSF TRISC, 1
BCF TRISD, 0
AGAIN BTFSS PORTC, 1
BRA AGAIN
MOVLW 0x08
MOVWF COUNT
MOVLW 0x55
BACK
RRCF WREG
BC ONE
BCF PORTD, 0
BRA OVER
ONE BSF PORTD, 0
OVER DECFSZ COUNT
BRA BACK
HERE BRA HERE
END

```

40. STATUS

41. Z flag is D2 of STATUS register.

42. a) valid: RB1 b) invalid c) valid: bit number 1 of WREG

d) valid: bit number 1 of RAM location 0x30 e) valid: RD0

f) (BTG) valid: C flag of STATUS register g) invalid h) invalid

NOTE: instructions in parts (g) and (h) do not have syntax error, but can not manipulate bits.

43. valid

44. All of them

45. The entire data RAM is bit-addressable.

46. BCF STATUS, 0 ; C flag is D0 of STATUS register

47. BC instruction

48. BZ instruction

49. C flag : bit 0, DC flag : bit 1, Z flag : bit 2, OV flag : bit 3

50. True

51. False

52.

```

AGAIN BTFSS STATUS, 0 ; C flag is D0 of STATUS register
BRA OVER
BSF 0x10, 4
BRA AGAIN
OVER BCF 0x10, 4
BRA AGAIN

```

53.

```
AGAIN BTFSS STATUS, 1 ; DC flag is D1 of STATUS register
BRA OVER
BSF 0x16,2
BRA AGAIN
OVER BCF 0x16,2
BRA AGAIN
```

40

54.

55.

```
AGAIN BTFSS STATUS, 2 ; Z flag is D2 of STATUS register
BRA OVER
BSF 0x12,7
BRA AGAIN
OVER BCF 0x12,7
BRA AGAIN
BTFSC WREG,0
BRA EXIT
BTFSC WREG,1
BRA EXIT
RRNCF WREG
RRNCF WREG
EXIT
```

56. In the following program we assume that LCD is connected to PORTB

```
ORG 0
CLRF TRISB,F
BTFSS WREG,7
BRA EXIT
MOVLW 0x00
MOVWF TBLPTRL
MOVLW 0x2
MOVWF TBLPTRH
NEXT TBLRD*+
MOVF TABLAT,W
BZ EXIT
MOVWF PORTB
CALL DISPLAY
BRA NEXT
EXIT BRA EXIT
ORG 200
DB "WREG CONTAINS A NEGATIVE VALUE",0
EXIT
END
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 41

57. Main part of program:

```
a) SETF 0x20,F
b) BSF 0x20,0
BSF 0x20,1
BSF 0x20,2
BSF 0x20,3
BSF 0x20,4
BSF 0x20,5
BSF 0x20,6
```

BSF 0x20,7

58. Bits 0-2 of values divisible by 8 are zero. So we test these bits of WREG.

```
ANDLW WREG,B'00000111'
```

```
BZ DIVISIBLE
```

```
; INSTRUCTIONS THAT SHOULD BE PERFORMED
```

```
; IN THE CASE THAT WREG IS NOT DIVISIBLE BY 8
```

```
-----
```

```
-----
```

```
DIVISIBLE:
```

```
; INSTRUCTIONS THAT SHOULD BE PERFORMED
```

```
; IN THE CASE THAT WREG IS DIVISIBLE BY 8
```

```
-----
```

```
-----
```

59.

```
RESULT EQU 0x20
```

```
COUNT_VAL EQU 0x8
```

```
COUNT_REG EQU 0x21
```

```
MYREG EQU 0x5
```

```
ORG 0
```

```
MOVLW COUNT_VAL
```

```
MOVWF COUNT_REG
```

```
MOVLW 0
```

```
MOVWF RESULT
```

```
BCF STATUS, 0 ; CLEAR CARRY FLAG
```

```
AGAIN RRCF MYREG,F
```

```
BC NEXT
```

```
INCF RESULT,F
```

```
NEXT DECF COUNT_REG,F
```

```
BNZ AGAIN
```

```
BRA $
```

```
END
```

42

SECTION 6.5: BANK SWITCHING IN THE PIC18

60. Direct - Register Indirect

61. Direct - Register Indirect

62. The lower 128 bytes of access bank are locations 00-7F of RAM . The upper 128 bytes of

access bank are locations F80-FFF of data RAM.

63. F80-FFF

64. 16

65. "ADDWF MYREG,F,0" adds the WREG to MYREG which is considered to be in access bank. "ADDWF MYREG,F,1" does the same, but considers MYREG register in the bank selected by BSR register.

66. We load the BSR register via immediate addressing mode and manipulate bank registers

via direct or register indirect addressing mode.

67.

```
COUNT_VAL EQU 0x0F
```

```
COUNT_REG EQU 0x20
```

```
ORG 0
```

```
MOVLW COUNT_VAL
```

```
MOVWF COUNT_REG
```

```
LFSR 0,0x1C0
```

```

MOVLW 0x55
NEXT MOVWF POSTINC0
DECF COUNT_REG, F
BNZ NEXT
BRA $
END
68.
COUNT_VAL EQU 0x0F
COUNT_REG EQU 0x5
ORG 0
MOVLW COUNT_VAL
MOVWF COUNT_REG
LFSR 0, 0x20
LFSR 1, 0x2D0
NEXT MOVFF POSTINC0, POSTINC1
DECF COUNT_REG, F
BNZ NEXT
BRA $
END

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 43

69. "CLRF MYREG,F,0" clears all the bits of MYREG which is considered to be in access

bank. "CLRF MYREG,F,1" does the same, but considers MYREG register in the bank selected by BSR register.

70. "SETF MYREG,F,0" sets all the bits of MYREG which is considered to be in access bank to high. "SETF MYREG,F,1" does the same, but considers MYREG register in the bank selected by BSR register.

71. "INCF MYREG,F,0" increases the contents of MYREG which is considered to be in access bank by 1. "INCF MYREG,F,1" does the same, but considers MYREG register in the bank selected by BSR register.

SECTION 6.6: CHECKSUM AND ASCII SUBROUTINES

72. We first add the corresponding ASCII values of characters in message "Hello" together:

$$s = 48h + 65h + 6Ch + 6Ch + 6Fh = 1F4h$$

Then we drop the carry and convert the remainder (F4h) to 2's complement form (0Ch) which is the check-sum.

73. True

74. #include P18F458.inc

```

RAM_ADDR EQU 40H ;RAM space to place the bytes
COUNTREG EQU 0x20 ;fileReg loc for counter
CNTVAL EQU 31 ;counter value = 4 for adding 4 bytes
CNTVAL1 EQU 32 ;counter value = 5 for adding 5 bytes
;including checksum byte
;-----main program
ORG 0
CALL COPY_DATA
CALL CAL_CHKSUM
CALL TEST_CHKSUM
BRA $
;-----copying data from code ROM address 500H to data RAM loc
COPY_DATA
MOVLW low(MYBYTE) ;WREG = 00 LOW-byte addr

```

```

MOVWF TBLPTRL ;ROM data LOW-byte addr
MOVLW hi(MYBYTE) ;WREG = 5, HIGH-byte addr
MOVWF TBLPTRH ;ROM data HIGH-byte addr
MOVLW upper(MYBYTE) ;WREG = 00 upper-byte addr
MOVWF TBLPTRU ;ROM data upper-byte addr
LFSR 0,RAM_ADDR ;FSR0 = RAM_ADDR, place to save
C1 TBLRD*+ ;bring in next byte and inc TBLPTR
MOVF TABLAT,W ;copy to WREG (Z = 1, if null)
BZ EXIT ;is it null char? exit if yes
MOVWF POSTINC0 ;copy WREG to RAM and inc pointer
BRA C1
EXIT RETURN
;-----calculating checksum byte
CAL_CHKSUM
MOVLW CNTVAL ;WREG = 4
MOVWF COUNTREG ;load the counter, count = 4
LFSR 0,RAM_ADDR ;load pointer. FSR0 = 40H
CLRF WREG
C2 ADDWF POSTINC0,W ;add RAM to WREG and increment FSR0
DECF COUNTREG,F ;decrement counter
BNZ C2 ;loop until counter = zero
44
XORLW 0xFF ;1's comp
ADDLW 1 ;2's compl
MOVWF POSTINC0
RETURN
;-----testing checksum byte
TEST_CHKSUM
MOVLW CNTVAL1 ;WREG = 5
MOVWF COUNTREG ;load the counter, count = 5
CLRF TRISB ;PORTB = output
LFSR 0,RAM_ADDR ;load pointer. FSR0 = 40H
CLRF WREG
C3 ADDWF POSTINC0,W ;add RAM and increment FSR0
DECF COUNTREG,F ;decrement counter
BNZ C3 ;loop until counter = zero
XORLW 0x0 ;EX-OR to see if WREG = zero
BZ G_1 ;is result zero? then good
MOVLW 'B'
MOVWF PORTB ;if not, data is bad
RETURN
G_1 MOVLW 'G'
MOVWF PORTB ;data is not corrupted
RETURN
;-----my data in program ROM
ORG 0x500
MYBYTE DB "Hello, my fellow world citizens"
END
75. ASCII
76.
ORG 0000
SETF TRISB
CLRF TRISD
NEXT MOVF PORTB, W
ANDLW 0x0F
CALL ASCII_TABLE

```

```

MOVWF PORTD
BRA NEXT
;----- TABLE PROCESSING
ASCII_TABLE
MULLW 0x2
MOVF PRODL, W
ADDWF PCL, F
DT "0123456789"
END

```

```

77. #include P18F458.inc

```

```

RAM_ADDR EQU 0x20

```

```

ASC_RAM EQU 0x40

```

```

COUNTREG EQU 0x1F ;fileReg loc for counter

```

```

CNTVAL EQU D'4' ;counter value of BCD bytes

```

```

CNTVAL1 EQU D'8' ;counter value of ASCII bytes

```

```

;-----main program

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 45

```

ORG 0

```

```

CALL COPY_DATA

```

```

CALL BCD_ASC_CONV

```

```

CALL DISPLAY

```

```

BRA $

```

```

;-----copying data from code ROM to data RAM

```

```

COPY_DATA

```

```

MOVLW low(MYBYTE) ;WREG = 00 LOW-byte addr

```

```

MOVWF TBLPTRL ;ROM data LOW-byte addr

```

```

MOVLW hi(MYBYTE) ;WREG = 5, HIGH-byte addr

```

```

MOVWF TBLPTRH ;ROM data HIGH-byte addr

```

```

MOVLW upper(MYBYTE) ;WREG = 00 upper-byte addr

```

```

MOVWF TBLPTRU ;ROM data upper-byte addr

```

```

LFSR 0, RAM_ADDR ;FSR0 = RAM_ADDR, place to save

```

```

C1 TBLRD*+ ;bring in next byte and inc TBLPTR

```

```

MOVF TABLAT, W ;copy to WREG (Z = 1, if null)

```

```

BZ EXIT ;is it null char? exit if yes

```

```

MOVWF POSTINC0 ;copy WREG to RAM and inc pointer

```

```

BRA C1

```

```

EXIT RETURN

```

```

;-----convert packed BCD to ASCII

```

```

BCD_ASC_CONV

```

```

MOVLW CNTVAL ;get the counter value

```

```

MOVWF COUNTREG ;load the counter

```

```

LFSR 0, RAM_ADDR ;FSR0 = RAM_ADR BCD byte pointer

```

```

LFSR 1, ASC_RAM ;FSR1 = ASC_RAM ASCII byte pointer

```

```

B2 MOVF INDF0, W ;copy BCD to WREG

```

```

ANDLW 0x0F ;mask the upper nibble (W = 09)

```

```

IORLW 0x30 ;make it an ASCII

```

```

MOVWF POSTINC1 ;copy to RAM and increment FSR1

```

```

MOVF POSTINC0, W ;note the use of instruction

```

```

ANDLW 0xF0 ;mask the lower nibble (W = 20H)

```

```

SWAPF WREG

```

```

IORLW 0x30 ;make it an ASCII

```

```

MOVWF POSTINC1 ;copy to RAM and increment FSR1

```

```

DECF COUNTREG, F ;decrement counter

```

```

BNZ B2 ;loop until counter = zero

```

```

RETURN

```

```

;-----send ASCII data to port B

```

```

DISPLAY
CLRF TRISB ;make PORTB output (TRISB = FFH)
MOVLW CNTVAL1 ;WREG = 8, send 8 bytes of data
MOVWF COUNTREG ;load the counter, count = 8
LFSR 2,ASC_RAM ;load pointer. FSR2 = 50H
B3 MOVF POSTINC2,W ;copy RAM to WREG and inc pointer
MOVWF PORTB ;copy WREG to PORTB
DECF COUNTREG,F ;decrement counter
BNZ B3 ;loop until counter = zero
RETURN
;-----my BCD data in program ROM
ORG 0x700
MYBYTE DB 76H, 87H, 98H, 43H, 00H
END

```

46

```

78.#include P18F458.INC
COUNT_VAL EQU 4
COUNT_REG EQU 0x20
MYBCD EQU 0x21
RAM_ADDR EQU 0x40
BCD_RAM EQU 0x60
; ----- main program
ORG 0
CALL COPY_DATA
CALL ASC_BCD_CONV
BRA $
;----- copying data from code ROM to data RAM
COPY_DATA
MOVLW 0x00
MOVWF TBLPTRL
MOVLW 0x03
MOVWF TBLPTRH
LFSR 0,RAM_ADDR
C1 TBLRD*+
MOVF TABLAT,W
BZ EXIT
MOVWF POSTINC0
BRA C1
EXIT RETURN
;----- convert ASCII to BCD
ASC_BCD_CONV
MOVLW COUNT_VAL
MOVWF COUNT_REG
LFSR 0,RAM_ADDR
LFSR 1,BCD_RAM
B1 MOVF POSTINC0,W
ANDLW 0x0F
MOVWF MYBCD
SWAPF MYBCD,F
MOVF POSTINC0,W
ANDLW 0x0F
IORWF MYBCD,W
MOVWF POSTINC1
DECF COUNT_REG,F
BNZ B1
RETURN

```

```
;----- My ASCII data in program ROM
ORG 300H
MYDATA DB "87675649"
END
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 47

79. If PORTD = 1000 1101 (141), the contents of RAM locations will be:

0x40 -- '1' = 0x31 0x41 -- '4' = 0x34 0x43 -- '1' = 0x39

```
#include P18F458.INC
```

```
NUM EQU 0x00 ;RAM loc for NUME
```

```
QU EQU 0x20 ;RAM loc for quotient
```

```
RMND_L EQU 0x40 ;the least significant digit loc
```

```
RMND_M EQU 0x41 ;the middle significant digit loc
```

```
RMND_H EQU 0x42 ;the most significant digit loc
```

```
MYDEN EQU D'10' ;value for divide by 10
```

```
COUNTREG EQU 0x10 ;fileReg loc for counter
```

```
CNTVAL EQU d'3' ;counter value
```

```
UNPBCD_ADDR EQU 0x30
```

```
ASCII_RESULT EQU 0x40
```

```
;-----main program
```

```
ORG 0
```

```
SETF TRSID ;make PORTD input
```

```
CALL BIN_DEC_CON
```

```
CALL DEC_ASCII_CON
```

```
BRA $
```

```
;-----converting BIN(HEX) TO DEC (00-FF TO 000-255)
```

```
BIN_DEC_CON
```

```
MOVFF PORTD,WREG ;get the binary data from PORTD
```

```
MOVWF NUME ;load numerator
```

```
MOVLW MYDEN ;WREG = 10, the denominator
```

```
CLRF QU ;clear quotient
```

```
D_1 INCF QU ;inc quotient for every subtraction
```

```
SUBWF NUME ;subtract WREG from NUME value
```

```
BC D_1 ;if positive go back
```

```
ADDWF NUME ;once too many, first digit
```

```
DECF QU ;once too many for quotient
```

```
MOVFF NUME,RMND_L ;save the first digit
```

```
MOVFF QU,NUME ;repeat the process one more time
```

```
CLRF QU ;clear QU
```

```
D_2 INCF QU
```

```
SUBWF NUME ;subtract WREG from NUME value
```

```
BC D_2
```

```
ADDWF NUME ;once too many
```

```
DECF QU
```

```
MOVFF NUME,RMND_M ;2nd digit
```

```
MOVFF QU,RMND_H ;3rd digit
```

```
RETURN
```

```
;----converting unpacked BCD digits to displayable ASCII digits
```

```
DEC_ASCII_CON
```

```
MOVLW CNTVAL ;WREG = 10
```

```
MOVWF COUNTREG ;load the counter, count = 10
```

```
LFSR 0,UNPBCD_ADDR ;load pointer FSR0
```

```
LFSR 1,ASCII_RESULT ;load pointer FSR1
```

```
B3 MOVF POSTINC0, W ;copy RAM to WREG, increment FSR0
```

```
ADDLW 0x30 ;make it an ASCII
```

```
MOVWF POSTINC1 ;copy WREG and increment FSR1
```

```
DECF COUNTREG,F ;decrement counter
```

```
BNZ B3 ;loop until counter = zero
RETURN
END ;end of the program
```

48

SECTION 6.7: MACROS AND MODULES

80. 1) The programs using MACROS are more readable.
- 2) MACROS do not use stacks and are not at the risk of stack overflow in nested form.
81. A MACRO - Because MACROS are replaced with their corresponding instructions in assembling process.
82. 1) Each module can be written, debugged and tested individually.
- 2) The failure of one module does not stop the entire project.
- 3) Parallel development of a large project.
83. extern
84. global
85. We write the main program as well as BIN_DEC_CON subroutine in one file

(main.asm)

and the DEC_ASCII_CON subroutine in another file (dec2ascii.asm)

```
;----- MAIN.ASM-CONVERTING BIN (HEX) TO ASCII
#include P18F458
NUM EQU 0x00
QU EQU 0x20
RMND_L EQU 0x30
RMND_M EQU 0x31
RMND_H EQU 0x32
MYDEN EQU D'10'
EXTERN DEC_ASCII_CON
PGM CODE
;----- main program
ORG 0000
CALL BIN_DEC_CON
CALL DEC_ASCII_CON
BRA $
;----- converting BIN(HEX) (00-FF) to decimal (000-255)
BIN_DEC_CON
MOVFF PORTB,WREG ;get the binary data from PORTB
MOVWF NUM ;load numerator
MOVLW MYDEN ;WREG = 10, the denominator
CLRF QU ;clear quotient
D_1 INCF QU ;inc quotient for every subtraction
SUBWF NUM ;subtract WREG from NUM value
BC D_1 ;if positive go back
ADDWF NUM ;once too many, first digit
DECF QU ;once too many for quotient
MOVFF NUM,RMND_L ;save the first digit
MOVFF QU,NUM ;repeat the process one more time
CLRF QU ;clear QU
D_2 INCF QU
SUBWF NUM ;subtract WREG from NUM value
BC D_2
ADDWF NUM ;once too many
DECF QU
MOVFF NUM,RMND_M ;2nd digit
MOVFF QU,RMND_H ;3rd digit
RETURN
```

END

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 49

In a separate file:

```
;----- DEC2ASCII.ASM-CONVERTING UNPACKED BCD DIGITS TO ASCII
#include P18F458
CNTVAL EQU 4
CNTVAL1 EQU 5
GLOBAL DEC_ASCII_CON
PGM CODE
DEC_ASCII_CON
MOVLW CNTVAL ;WREG = 10
MOVWF COUNTREG ;load the counter, count = 10
LFSR 0,UNPBCD_ADDR ;load pointer FSR0
LFSR 1,ASCII_RESULT ;load pointer FSR1
B3 MOVF POSTINC0, W ;copy RAM to WREG, increment FSR0
ADDLW 0x30 ;make it an ASCII
MOVWF POSTINC1 ;copy WREG and increment FSR1
DECF COUNTREG,F ;decrement counter
BNZ B3 ;loop until counter = zero
RETURN
END ;end of the program
```

50

CHAPTER 7: PIC PROGRAMMING IN C

SECTION 7.1: DATA TYPES AND TIME DELAYS IN C

1. a) signed char b) unsigned char c) unsigned int
d) unsigned char e) unsigned char f) unsigned char
g) unsigned int h) unsigned char i) unsigned char
2. a) 0E H b) 18 H c) 41 H
d) 07 H e) 20 H f) 45 H
g) FF H h) 0F H
3. a) Crystal frequency
b) The way the C compiler compiles (depends on the compiler type)
Note: We assume the PIC18 family has 4 clock periods / machine cycle.
4. Crystal frequency (also choice over compiler should be taken into consideration)
5. No, that is an internal factor which is not under programmer's control. It is determined and designed by the IC designer.
6. Because in the compilation of the C code into assembly, different compilers use different methods based on their design and optimization which results in different hex file sizes.

SECTION 7.2: I/O PROGRAMMING IN C

7. The former refers to pin RB4 (pin no.37), but the latter is an internal signal which determines whether RB4 is input or output.
8. The following program toggles all bits of PORTB in 200msec intervals.

```
#include <P18F458.h>
void MSDelay (unsigned int);
void main (void){
    TRISB = 0;
    PORTB = 0x55;
    while (1){
        MSDelay (200);
        PORTB = ~PORTB;
```

```

}
}
void MSDelay (unsigned int itime){
unsigned int I; unsigned char j;
for ( i = 0 ; i < itime ; i++ )
for ( j = 0 ; j < 165 ; j++ );
}

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 51

9.

```

10. void MyDelay (void){
unsigned char i,j;
for ( i = 0 ; i < 100 ; i++ )
for ( j = 0 ; j < 165 ; j++ );
}

```

```

#include <P18F458.h>
#define pin PORTBbits.RB0
void MyDelay ( void );
void main ( void ){
TRISBbits.TRISB0 = 0;
pin = 1;
while ( 1 ){
pin = ~pin;
MyDelay ();
}
}

```

```

void MyDelay ( void ){
unsigned char i,j;
for ( i = 0 ; i < 200 ; i++ )
for ( j = 0 ; j < 165 ; j++ );
}

```

```

#include <P18F458.h>
void MSDelay (unsigned int);
void main (void){
TRISBbits.TRISB1 = 0;
TRISBbits.TRISB7 = 0;
PORTBbits.RB1 = 1;
PORTBbits.RB7 = 1;
while (1){
MSDelay (200);
PORTB = PORTB ^ 0x82;
}
}

```

```

void MSDelay (unsigned int itime){
unsigned int i; unsigned char j;
for ( i = 0 ; i < itime ; i++ )
for ( j = 0 ; j < 165 ; j++ );
}

```

11.

52

12.

SECTION 7.3: LOGIC OPERATIONS IN C

13. a) PORTB = 40H b) PORTB = 50H c) PORTB = 86H
- d) PORTC = 90H e) PORTC = 60H f) PORTC = F0H
- g) PORTC = F0H h) PORTC = F9H i) PORTC = 1EH

j) PORTC = 5AH

14. a) PORTB = 64H b) PORTB = 7BH c) PORTC = 3FH

d) PORTC = 58H e) PORTC = D7H f) PORTD = 04H

g) PORTB = 37H

15. a) PORTB = 19H b) PORTC = E4H c) PORTB = 1AH

d) PORTB = 9CH

```
16. #include <P18F458.h>
unsigned char swap(unsigned char);
void main (void){
    TRISB = 0;
    unsigned char myNum = 0x95;
    PORTB = swap(myNum);
    while (1);
}
unsigned char swap (unsigned char charNum){
    unsigned char n;
    n = charNum & 0x0F;
    n = n << 4;
    charNum = charNum >> 4;
    n = n | charNum;
    return n;
}
#include <P18F458.h>
void MyDelay ( void );
void main ( void ){
    unsigned char x;
    TRISB = 0;
    while ( 1 ){
        for (x = 0; x <= 99; x++){
            PORTB = x;
            MyDelay();
        }
    }
}
void MyDelay ( void ){
    unsigned char i,j;
    for ( i = 0 ; i < 200 ; i++ )
        for ( j = 0 ; j < 165 ; j++ );
}
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 53

17. The following program reads the present byte on PORTB port continuously and shows

the number of zeros on PORTC.

```
#include <P18F458.h>
unsigned char zeroCount (unsigned char);
void main (void){
    unsigned char myNum;
    TRISB = 255;
    TRISC = 0;
    while (1){
        myNum = PORTB;
        PORTC = zeroCount(myNum);
    }
}
```

```

unsigned char zeroCount (unsigned char charNum){
unsigned char j , k = 0;
for (j = 0 ; j < 8 ; j++ ){
if (( charNum & 0x01 ) == 0 )
k++;
charNum = charNum >> 1;
}
return k;
}

```

18.

```

#include <P18F458.h>
void main void){
TRISB = 0;
unsigned char pattern = 0x0C;
while ( 1 ){
PORTB = pattern;
pattern = pattern >> 1;
if ( pattern == 4 )
pattern = 0x0C;
if ( pattern == 1 )
pattern = 0x09;
}
}

```

54

SECTION 7.4: DATA CONVERSION PROGRAMS IN C

19. The following program converts the given bytes into two ASCII bytes and sends these

two ASCII bytes into ports PORTB and PORTC.

```

#include <P18F458.h>
unsigned char bcdNum[4] = { 0x76 , 0x87 , 0x98 , 0x43 };
void BCDtoASCII (unsigned char);
void main (void){
unsigned char j;
TRISB = 0;
TRISC = 0;
for ( j = 0 ; j < 4 ; j++ )
BCDtoASCII (bcdNum[j]);
while(1);
}
void BCDtoASCII (unsigned char charNum){
unsigned char Temp;
Temp = charNum & 0xF0;
charNum = charNum & 0x0F;
PORTB = charNum | 0x30;
Temp = Temp >> 4;
PORTC = Temp | 0x30;
}

```

20. The following program converts the string into packed BCD format and shows high-byte

to PORTB and low-byte to PORTC.

```

#include <P18F458.h>
char str[] = "8767";
void main ( void ){
TRISC = 0;
TRISB = 0;

```

```

unsigned char lowByte , highByte;
highByte = str[0] & 0x0F;
highByte = highByte << 4;
highByte = highByte | (str[1] & 0x0F);
PORTB = highByte;
lowByte = str[2] & 0x0F;
lowByte = lowByte << 4;
lowByte = lowByte | (str[3] & 0x0F);
PORTC = lowByte;
}

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 55

21. The following program gets an 8-bit data from PORTB and sends its ASCII equivalent to

PORTD-PORTC if it is less than 100.

```

#include <P18F458.h>
void main (void){
    TRISB = 255;
    TRISC = 0;
    TRICD = 0;
    unsigned char num,D3,D2,D1;
    // num will be converted to D3-D2-D1
    while (1){
        num = PORTB;
        D1 = ( num % 10 ) | 0x30; // LSD
        num = num / 10;
        D2 = ( num % 10 ) | 0x30;
        D3 = num / 10; // MSD
        if ( D3 == 0 ){ // 0 <= num <= 99
            PORTC = D1;
            PORTD = D2;
        }
    }
}

```

If PORTB = 10001001b, it represents decimal number of 137 which cannot be a packed BCD number stored in just one byte. So, in this case the above program will not send any data bytes to PORTC and PORTD.

SECTION 7.6: PROGRAM ROM ALLOCATION IN C18

22. a) data RAM b) code ROM c) code ROM d) code ROM

23. False

24. 1) Saving data RAM space (this type of data usually needs a lot of space).

2) They are usually fixed. We use ROM to save fixed data and RAM to store variable data.

25. 1) Much more storage space

2) Not occupying RAM space which may be needed for storing some essential data

26. 1) Data stored in ROM space can not be changed unless with re-programming.

2) The more code space we use for data, the less is left for instructions.

27.

```

#include <P18F458.h>
rom const unsigned char myName[] = "Javad Rasti";
void main ( void ){
    unsigned char z = 0;
    TRISC = 0;
    while ( myName[z] != '\0' )

```

```
PORTC = myName[z++];
}
```

56

28. When "near" qualifier is used, the corresponding data will be stored within the first 64KB

of ROM. Using "far" qualifier lets the data be stored in the whole 2MB space ROM.

29. "#pragma code" is used to place the code at a specific address location of program ROM.

"#pragma romdata" is used to place the data at a specific location of program ROM.

30. .

```
#include <P18F458.h>
#pragma romdata first_name = 0x220
#pragma romdata last_name = 0x200
rom const unsigned char first_name[] = "Javad";
rom const unsigned char last_name[] = "Rasti";
void main ( void ){
unsigned char z = 0;
TRISC = 0;
while ( first_name[z] != '\0' )
PORTC = first_name[z++];
z = 0;
while ( last_name[z] != '\0' )
PORTC = last_name[z++];
}
```

31. a) 32K b) 32K c) 128K

32. The more code space we use for data, the less is left for instructions.

SECTION 7.7: DATA RAM ALLOCATION IN C

33. a) data RAM b) data RAM c) data RAM d) data RAM

e) code ROM

34. a) 1536 bytes b) 1536 bytes c) 3936 bytes

35. All the PIC18 products have the bank size of 256 bytes. If we want to create a portable

program which can run on all PIC18 products, we must limit the array size to fit into a single bank.

36. 1) Saving data RAM space (this type of data usually needs a lot of space).

2) They are usually fixed. We use ROM to save fixed data and RAM to store variable data.

37. There will be a little space left for our program variables. ROM is more appropriate to store fixed data.

38. They can be changed easily during system operation.

39. "#pragma idata" is used to declare initialized variables at a specific location of data RAM, while "#pragma udata" is used for un-initialized data.

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 57

40.

```
#include <P18F458.h>
unsigned char myName[] = "Javad Rasti";
void main ( void ){
unsigned char z = 0;
TRISC = 0;
while ( myName[z] != '\0' )
PORTC = myName[z++];
}
```

}

41. Using "overlay" lets the compiler use a common location to store two or more variables

(if they are not active at the same time). This method saves memory.

42. True

58

CHAPTER 8: PIC18F HARDWARE CONNECTION AND ROM LOADERS

SECTION 8.1: PIC18F458/452 PIN CONNECTION

1. 40

2. Pins 11 and 32 for V_{dd} and pins 12 and 31 for GND.

3. 33 I/O pins

4. 13 and 14

5. 40 MHz

6. Pin number 1

7. Master Clear

8. High, Low

9. 0000

10. 00

11. 00

12. 0xFF

13. 2

14. 2

15. OSC2

16. Input

17. Input

18. 7 pins: pins 2-7 and pin 14

19. 8 pins: pins 33-40

20. 8 pins: pins 15-18 and pins 23-26

21. 8 pins: pins 19-22 and pins 27-30

22. Input

23. PORTE

24. RB4

SECTION 8.2: PIC18 CONFIGURATION REGISTERS

25. True

26. True

27. False

28. False

29. True

30. False

31. 0x300001, 0x300002, 0x300003, 0x300006

32. 8

33. CONFIG1H

34. CONFIG2L

35. CONFIG2H

36. If the V_{dd} falls below 4.2 (v), the CPU will go into the reset state and stops execution of programs without losing any data in registers. When V_{dd} rises above 4.2(v), the CPU will come out of reset and continue the program execution.

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 59

37. CONFIG OSC = HS, OSCS = OFF, BORV = 42, PWRT = ON, WDT = OFF
CONFIG DEBUG = OFF, LVP = OFF, STVR = OFF

38. LP

39. CONFIG1H

40. (a) $12 \text{ MHz} / 4 = 3 \text{ MHz}$ and the instruction cycle time = $1 / (3 \text{ MHz}) = 333 \text{ ns}$

(b) $20 \text{ MHz} / 4 = 5 \text{ MHz}$ and the instruction cycle time = $1 / (5 \text{ MHz}) = 200 \text{ ns}$

(c) $25 \text{ MHz} / 4 = 6.25 \text{ MHz}$ and the instruction cycle time = $1 / (6.25 \text{ MHz}) = 160 \text{ ns}$

(d) $30 \text{ MHz} / 4 = 7.5 \text{ MHz}$ and the instruction cycle time = $1 / (7.5 \text{ MHz}) = 133.33 \text{ ns}$

SECTION 8.3: EXPLAINING THE INTEL HEX FILE FOR PIC18

41. True

42. True

43. False

44. True

45. False- ROM size is limited to 4 gigabytes.

46. (1) The colon starts the line.

(2) The first byte after the colon (10h) indicates that there will be 16 data bytes in this line.

(3) The next two bytes (0000h) indicate the ROM address that the first data byte must be burned into.

(4) The next byte (00h) shows that this is not the last line of the program.

(5) The next sixteen bytes are the op-codes and their operand data.

(6) The last byte is the check-sum byte of the previous bytes in the line.

47. Calculation of the check-sum byte:

$10\text{h} + 00\text{h} + 00\text{h} + 00\text{h} + 93\text{h} + 6\text{Ah} + 55\text{h} + 0\text{Eh} + 81\text{h} + 6\text{Eh} + 81\text{h} + 1\text{Eh} + 07\text{h} + \text{ECh} + 00\text{h} + \text{F0h} + \text{FCh} + \text{D7h} + 02\text{h} + 0\text{Eh} = 6\text{C4h}$

Dropping the carries: C4h

2's complement of C4h: 3Ch (which is the last byte of line 1)

Verification of the check-sum byte: $10\text{h} + 00\text{h} + \dots + 02\text{h} + 0\text{Eh} + 3\text{Ch} = 700\text{h}$

Dropping the carries: 00h. So 3Ch is the correct check-sum byte of the line.

48. Calculation of the check-sum byte:

$0\text{Eh} + 00\text{h} + 00\text{h} + 00\text{h} + 93\text{h} + 6\text{Ah} + 55\text{h} + 0\text{Eh} + 81\text{h} + 6\text{Eh} + 81\text{h} + 1\text{Eh} + 78\text{h} + \text{ECh} + 94\text{h} + \text{F0h} + \text{FCh} + \text{D7h} = 7\text{B7h}$

Dropping the carries: B7h

2's complement of B7h: 49h (which is the last byte of line 2)

Verification of the check-sum byte: $0\text{Eh} + 00\text{h} + \dots + \text{FCh} + \text{D7h} + 49\text{h} = 800\text{h}$

Dropping the carries: 00h. So 49h is the correct check-sum byte of the line.

49. INTHX8M is used for codes with size below 64 Kbytes. INTHX32 is used for codes with size up to 4 Gigabytes. They also differ in TT field of each line.

50. In line 4, after the colon (:), we have 10H (which is 16 in decimal) as the number of bytes in this line. The AAAA = 28F0 is the lower 16-bit address where information will be burned. Next, 00 means that this is not the last line of the record. Then the data, which is 16 bytes, is as follows: 020E076EFA0E086EFA0E096E00000000. Finally, the last byte, 56, is the checksum byte.

60

SECTION 8.4: PIC18 TRAINER DESIGN AND LOADING OPTIONS

51. False

52. True

53. (b)

54. 54.

```
SETF TRISB ;Define PORTB as input
CLRF TRISC ;Define PORTC as output
CLRF TRISD ;Define PORTD as output
MOVFF PORTB, PORTC
MOVFF PORTB, PORTD
```

55. 55.

```
SETF TRISD ;Define PORTD as input
CLRF TRISB ;Define PORTB as output
CLRF TRISC ;Define PORTC as output
MOVFF PORTD, PORTB
MOVFF PORTD, PORTC
```

56. Pin 40 (RB7) is PGD and pin 39 (RB6) is PGC.

57. 0000. It implies we must place our codes starting at address 0000.

58. (a) (b)

```
CLRF TRISB
BACK MOVLW 55H
MOVWF PORTB
CALL DELAY
MOVLW 0AAH
MOVWF PORTB
CALL DELAY
GOTO BACK
CLRF TRISB
MOVLW 55H
MOVWF PORTB
BACK CALL DELAY
COMF PORTB
BRA BACK
```

59. 7FFFh

60. 1FFFFh

61. 7FFFh

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 61

CHAPTER 9: PIC18 TIMER PROGRAMMING IN ASSEMBLY AND C

SECTION 9.1: PROGRAMMING TIMERS 0 AND 1

1. 4 timers

2. Timer0 is 16-bit and are accessed as low and high byte

3. Timer1 is 16-bit and are accessed as low and high byte

4. 256

5. 8

6. 8

7. Used for control of Timer0

8. True

9. 0x01

10. frequency = 10 MHz / 4 = 2.5 MHz period = 1 / (2.5 MHz) = 0.4 μ s

b) frequency = 20 MHz / 4 = 5 MHz period = 1 / (5 MHz) = 0.2 μ s

c) frequency = 24 MHz / 4 = 6 MHz period = 1 / (6 MHz) = 0.166 μ s

d) frequency = 30 MHz / 4 = 7.5 MHz period = 1 / (7.5 MHz) = 0.133 μ s

11. a) INTCON b) PIR1
12. a) FFFFH to 0000H = 65535 to 0 b) FFH to 00H = 255 to 0
13. a) When the timer reaches its maximum value of FFFFH and it rolls over to 0000
b) When the timer reaches its maximum value of FFH and it rolls over to 00
14. True
15. True
16. $10 \text{ MHz} / 4 = 2.5 \text{ MHz}$, $1 / 2.5 \text{ MHz} = 0.4 \mu\text{s}$,
 $2 \text{ ms} / 0.4 \mu\text{s} = 5000$, $65536 - 5000 = 60536 = 0xEC78$,
TMR0H = 0xEC TMR0L = 0x78
17. $10 \text{ MHz} / 4 = 2.5 \text{ MHz}$, $1 / 2.5 \text{ MHz} = 0.4 \mu\text{s}$,
 $5 \text{ ms} / 0.4 \mu\text{s} = 12500$, $12500 / 256 = 49$, $65536 - 49 = 65487 = 0xFFCF$,
TMR0H = 0xFF TMR0L = 0xCF
18. TMR1H = 0xFC TMR1L = 0xF2
19. TMR1H = 0xFE TMR1L = 0x0C
20. TMR1H = 0xFB TMR1L = 0x1E
21. $10 \text{ MHz} / 4 = 2.5 \text{ MHz}$, $2.5 \text{ MHz} / 256 = 9765.625 \text{ Hz}$,
 $1 / 9765.625 \text{ Hz} = 102.4 \mu\text{s}$, $102.4 \mu\text{s} * 65536 = 6.7108864 \text{ s}$,
 $6.7108864 \text{ s} * 2 = 13.4217728 \text{ s}$, $1 / 13.4217728 = 0.0745058 \text{ Hz}$
So the lowest frequency is equal to 0.0745058 HZ.
22. $10 \text{ MHz} / 4 = 2.5 \text{ MHz}$, $1 / 2.5 \text{ MHz} = 0.4 \mu\text{s}$,
Solution a) if we include 7 overhead instructions in the loop we have the following:
 $0.4 \mu\text{s} * 7 = 2.8 \mu\text{s}$, $T = 2.8 \mu\text{s} * 2 = 5.6 \mu\text{s}$, $F = 1 / T = 1 / 5.6 \mu\text{s} = 178. \text{ kHz}$
Solution b) if we ignore the overhead instructions in the loop we have the following:
Since Timer0 must have FFFFH to get the shortest period, $T = 0.4 \mu\text{s} * 2 = 0.8 \mu\text{s}$,
 $F = 1 / T = 1 / 0.8 \mu\text{s} = 1.25 \text{ MHz}$
23. 19.07 HZ
- 208.5 kHz (same as 22 with 6 overhead instructions)
24. F1H, F2H, F3H, ..., FFH, 00H = 16 states

62

25. Program:

```
#include <p18F458.inc>
ORG 0x00
GOTO START
ORG 0x30
START BCF TRISB, 4
MOVLW 0x08
MOVWF T0CON
HERE MOVLW 0xFB
MOVWF TMR0H
MOVLW 0x1E
MOVWF TMR0L
BCF INTCON, TMR0IF
CALL DELAY
BTG PORTB, RB4
BRA HERE
DELAY BSF T0CON, TMR0ON
AGAIN BTFSS INTCON, TMR0IF
```

```

BRA AGAIN
BCF T0CON, TMR0ON
RETURN
END
26. Program:
#include <p18F458.inc>
ORG 0x00
GOTO START
ORG 0x30
START BCF TRISB, 5
MOVLW 0x30
MOVWF T1CON
HERE MOVLW 0xFF
MOVWF TMR1H
MOVLW 0xCB
MOVWF TMR1L
BCF PIR1, TMR1IF
CALL DELAY
BTG PORTB, RB5
BRA HERE
DELAY BSF T1CON, TMR1ON
AGAIN BTFSS PIR1, TMR1IF
BRA AGAIN
BCF PIR1, TMR1ON
RETURN
END

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 63

27. Timer0 is 8 or 16 bit timer/counter. It has an interrupt on overflow from FFH to 00H in 8

bit and FFFFH to 0000H in 16 bit. Timer1 is only 16 bit timer/counter and it has interrupt on overflow from FFFFH to 0000H. The maximum prescaler supported by Timer0 is 256. The maximum prescaler supported by Timer1 is 8. Timer1 resets from CCP module special event register.

28. a) 0xF4

b) 0xEA

c) 0xDE

d) 0xA4

e) 0x88

f) 0x98

SECTION 9.2: COUNTER PROGRAMMING

29. We must set T0CS bit of T0CON to high

30. Yes

31. RA4/T0CKI pin

32. RC0/T1CKI pin

33. Program:

```

#include <p18F458.inc>
ORG 0x00

```

```

GOTO START
ORG 0x30
START BSF TRISC,0
CLRF TRISB
CLRF TRISD
MOVLW 0x02
MOVWF T1CON
HERE MOVLW 0x4E
MOVWF TMR1H
MOVLW 0x20
MOVWF TMR1L
BCF PIR1,TMR1IF
BSF T1CON,TMR1ON
AGAIN MOVFF TMR1H,PORTD
MOVFF TMR1L,PORTB
BTFSS PIR1,TMR1IF
BRA AGAIN
BCF T1CON,TMR1ON
GOTO HERE
END

```

34. Program:

```
#include <p18F458.inc>
```

```
ORG 0x00
```

```
GOTO START
```

```
ORG 0x30
```

```
64
```

```
START BSF TRISA,RA4
```

```
CLRF TRISB
```

```
MOVLW 0x68
```

```
MOVWF T0CON
```

```
HERE
```

```
MOVLW 0x14
```

```
MOVWF TMR0L
```

```
BCF INTCON,TMR0IF
```

```
BSF T0CON,TMR0ON
```

```
AGAIN
```

```
MOVFF TMR0L,PORTB
```

```
BTFSS INTCON,TMR0IF
```

```
BRA AGAIN
```

```
BCF T0CON,TMR0ON
```

```
GOTO HERE
```

```
END
```

35. 8

36. False

SECTION 9.3: PROGRAMMING TIMER 0 AND 1 IN C

37.

C Program:

```

#include <p18f458.h>
void ToDelay (void);
void main(void)
{
    TRISBbits.TRISB4=0;
    T0CON = 0x08;
    while(1)
    {
        PORTBbits.RB4 = 1;
        ToDelay();
        PORTBbits.RB4 = 0;
        ToDelay();
    }
}
void ToDelay()
{
    TMR0H = 0xFB;
    TMR0L = 0x1E;
    T0CONbits.TMR0ON = 1;
    while (INTCONbits.TMR0IF == 0);
    T0CONbits.TMR0ON = 0;
    INTCONbits.TMR0IF = 0;
}

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 65

38. C Program:

```

#include <p18f458.h>
void ToDelay(void);
void main(void)
{
    TRISBbits.TRISB4=0;
    T1CON = 0x0;
    while(1)
    {
        PORTBbits.RB4 = 1;
        ToDelay();
        PORTBbits.RB4 = 0;
        ToDelay();
    }
}
void ToDelay()
{
    TMR1H = 0xFB;
    TMR1L = 0x1E;
    T1CONbits.TMR1ON = 1;
    while (PIR1bits.TMR1IF == 0);
    T1CONbits.TMR1ON = 0;
    PIR1bits.TMR1IF = 0;
}

```

```

}
39. C Program:
#include <p18f458.h>
void ToDelay(void);
void main(void)
{
    TRISBbits.TRISB4=0;
    T0CON = 0x08;
    while(1)
    {
        PORTBbits.RB4 = 1;
        ToDelay();
        PORTBbits.RB4 = 0;
        ToDelay();
    }
}
void ToDelay()
{
    TMR0H = 0xFE;
    TMR0L = 0xC7;
66
    T0CONbits.TMR0ON = 1;
    while (INTCONbits.TMR0IF == 0);
    T0CONbits.TMR0ON = 0;
    INTCONbits.TMR0IF = 0;
}
40. C Program:
#include <p18f458.h>
void ToDelay(void);
void main(void)
{
    TRISBbits.TRISB4=0;
    T1CON = 0x0;
    while(1)
    {
        PORTBbits.RB4 = 1;
        ToDelay();
        PORTBbits.RB4 = 0;
        ToDelay();
    }
}
void ToDelay()
{
    TMR1H = 0xFE;
    TMR1L = 0xCB;
    T1CONbits.TMR1ON = 1;
    while (PIR1bits.TMR1IF == 0);

```

```
T1CONbits.TMR1ON = 0;
PIR1bits.TMR1IF = 0;
}
```

41. C Program:

```
#include <p18f458.h>
```

```
void main(void)
```

```
{
```

```
TRISCbits.TRISC4=1;
```

```
TRISB = 0x0;
```

```
TRISD = 0x00;
```

```
T1CON = 0x02;
```

```
while(1)
```

```
{
```

```
TMR1H = 0x4E;
```

```
TMR1L = 0x20;
```

```
T1CONbits.TMR1ON = 1;
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 67

```
do
```

```
{
```

```
PORTD = TMR1H;
```

```
PORTB = TMR1L;
```

```
} while(PIR1bits.TMR1IF == 0);
```

```
T1CONbits.TMR1ON = 0;
```

```
PIR1bits.TMR1IF = 0;
```

```
}
```

```
}
```

42. C Program:

```
#include <p18f458.h>
```

```
void main(void)
```

```
{
```

```
TRISAbits.TRISA4=1;
```

```
TRISD = 0x00;
```

```
T0CON = 0x68;
```

```
while(1)
```

```
{
```

```
TMR1L = 0x14;
```

```
T0CONbits.TMR0ON = 1;
```

```
do
```

```
{
```

```
PORTD = TMR0L;
```

```
} while(INTCONbits.TMR0IF == 0);
```

```
T0CONbits.TMR0ON = 0;
```

```
INTCONbits.TMR0IF = 0;
```

```
}
```

SECTION 9.4: PROGRAMMING TIMERS 2 AND 3

43. a) 1:16 b) 1:8

44. FFFFH to 0000H

45. a) When TMR2 = PR2 b) When TMR3H:TMR3L rolls over from FFFFH to 0000H

46. True

47. False

48. TMR3H = 0xEC TMR3L = 0x78

49. TMR3H = 0xF9 TMR3L = 0xE5

50. C Program:

```
#include <p18f458.h>
void main(void)
{
    TRISCbits.TRISC0 = 1;
    68
    TRISB = 0;
    TRISD = 0;
    T3CON = 0x02;
    TMR3H = 0x4E;
    TMR3L = 0x20;
    while (1)
    {
        T3CONbits.TMR3ON = 1;
        do
        {
            PORTB = TMR3L;
            PORTD = TMR3H;
        }while (PIR2bits.TMR3IF == 0);
        T3CONbits.TMR3ON = 0;
        PIR2bits.TMR3IF = 0;
    }
}
```

51. Assembly Program:

```
BCF TRISB, 3
BCF PORTB, 3
CLRF T2CON
CLRF TMR2
MOVLW 0xC8 ;200
MOVWF PR2
BCF PIR1, TMR2IF
BSF T2CON, TMR2ON
START:
    BTFSS PIR1, TMR2IF
    GOTO START
    BTG PORTB, 3
    GOTO START
```

52. C Program:

```
#include <p18f458.h>
void ToDelay(void);
void main(void)
{
```

```

TRISBbits.TRISB4=0;
T3CON = 0x0;
while(1)
{
PORTBbits.RB4 = 1;
ToDelay();
PORTBbits.RB4 = 0;
ToDelay();
}
}

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 69

```

void ToDelay()
{
TMR3H = 0xFE;
TMR3L = 0x5F;
PIR2bits.TMR3IF = 0;
T3CONbits.TMR3ON = 1;
while (PIR2bits.TMR3IF == 0);
T3CONbits.TMR3ON = 0;
PIR2bits.TMR3IF = 0;
}

```

53. C Program:

```

#include <p18f458.h>
void main(void)
{
TRISBbits.TRISB3 = 0;
PORTBbits.RB3 = 0;
T2CON = 0x00;
TMR2 = 0x00;
PR2 = 0xC8;
PIR1bits.TMR2IF = 0;
T2CONbits.TMR2ON = 1;
do
{
while (PIR1bits.TMR2IF == 0);
PORTBbits.RB3 = ~PORTBbits.RB3;
}while(1);
}

```

54. C Program:

```

#include <p18f458.h>
void ToDelay(void);
void main(void)
{
TRISBbits.TRISB4=0;
T3CON = 0x0;
while(1)
{

```

```

PORTBbits.RB4 = 1;
ToDelay();
PORTBbits.RB4 = 0;
ToDelay();
}
}
70
void ToDelay()
{
TMR3H = 0xFB;
TMR3L = 0x1E;
PIR2bits.TMR3IF = 0;
T3CONbits.TMR3ON = 1;
while (PIR2bits.TMR3IF == 0);
T3CONbits.TMR3ON = 0;
PIR2bits.TMR3IF = 0;
}

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 71
CHAPTER 10: PIC18 SERIAL PORT PROGRAMMING IN ASSEMBLY AND C
SECTION 10.1: BASICS OF SERIAL COMMUNICATION

1. Parallel
2. False
3. 1010110100 ---> this start bit goes first
4. Mark
5. False. It can be 1 or 2 but we always need stop bit.
6. 7 bit data + 1 stop bit + 1 start bit = 9 bits
 $2/9 \times 100 = 22\%$
7. False
8. It makes the RS232 standard compatible with TTL logic level.
9. False
10. 9 pins, since the rest are not involved in data transfer.
11. False
12. 3: Tx D Rx D Gnd
13. DTE -to- DTE
14. DCD, Rx D, Tx D, DTR, Gnd, DSR, RTS, CTS, RI
15. 4,000,000 bits (200 x 80 x 25 x 10)
16. 416.6 seconds

SECTION 10.2: PIC18 CONNECTION TO RS232

17. 16
18. VCC = 16, GND = 15
19. 20
20. VCC = 7, GND = 6
21. No
22. The MAX233 does not require an external capacitor, but it is more expensive.
23. 2
24. 2
- 25.

72

26.

27. It does not need the four capacitors that the MAX232 must have.

28. pin 25 – TxD (RC6), pin 26 – RxD (RC7)

SECTION 10.3: PIC18 SERIAL PORT PROGRAMMING IN ASSEMBLY

29. (a), (c), (e), (f)

30. None. It has its own timer

31. Bit D2 (BRGH)

32. To send a byte serially it must be placed in the TXREG register.

33. 8

34. It controls the framing of the data for serial ports.

35. 8

36. First we have $10\text{ MHz}/4 = 2.5\text{ MHz}$ and $2.5/16 = 156,250$.

Now each is calculated by using $X = (156,250/\text{Desired Baud Rate}) - 1$ formula..

(a) $156,250/9600 - 1 = 15 = \text{F}$ in hex

(b) $156,250/4800 - 1 = 32 = 20$ in hex

(c) $156,250/1200 - 1 = 129 = 81$ in hex

37. 9600

38.

```
MOVLW B'00100000'
```

```
MOVWF TXSTA
```

```
MOVLW 0x81 ;1200 bps (Fosc / (64 * Speed) - 1)
```

```
MOVWF SPBRG ;write to reg
```

```
BCF TRISC, TX ;make TX pin of PORTC an output pin
```

```
BSF RCSTA, SPEN ;Enable Serial port of PIC18
```

```
OVER BTFSS PIR1, TXIF ;wait until the last bit is gone
```

```
BRA OVER ;stay in loop
```

```
MOVLW A'Z' ;ASCII letter "Z" to be transferred
```

```
MOVWF TXREG ;load the value to be transferred
```

```
BRA OVER ;keep sending letter 'G'
```

```
END
```

39.

```
BCF TRISC, TX ;make TX pin of PORTC an output pin
```

```
BSF RCSTA, SPEN ;Enable the entire Serial port of PIC18
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 73

```
MOVLW 0x20 ;transmit at Low Baud rate
```

```
MOVWF TXSTA ;write to reg
```

```
MOVLW D'2' ;57600 bps (Fosc / (64 * Speed) - 1)
```

```
MOVWF SPBRG ;write to reg
```

```
OVER
```

```
MOVLW upper(MESSAGE)
```

```
MOVWF TBLPTRU
```

```
MOVLW high(MESSAGE)
```

```
MOVWF TBLPTRH
```

```
MOVLW low(MESSAGE)
```

```
MOVWF TBLPTRL
```

```
NEXT TBLRD*+ ;read the characters
```

```

MOVW TABLAT,W ;place it in WREG
BZ OVER ;if end of line, start over
CALL SENDCOM ;send char to serial port
BRA NEXT ;repeat for the next character
;-----
SENDCOM
S1 BTFSS PIR1, TXIF ;wait until the last bit is gone
BRA S1 ;stay in loop
MOVWF TXREG ;load the value to be transmitted
RETURN ;return to caller
;-----
MESSAGE:DB "The Earth is but One Country",0
END

```

40. TXIF flag is raised when a byte of data is transmitted and TXREG register is empty. It is

cleared when a new byte is written to TXREG.

41. RCIF flag is raised when a byte of data is received and it is sitting in RCREG register. It

is cleared when the content of RCREG is copied into another register.

42. PIR1, Yes

43. SPEN bit enables or disables serial data transmission/reception

44. BCF RCSTA,SREN

45. It belongs to the TXSTA register. Upon power on reset, BRGH = 0. By making BRGH =

1, it allows us to quadruple the serial data transfer rate with the same crystal.

46. Low

47. First we have $16 \text{ MHz}/4 = 4 \text{ MHz}$ and $4 \text{ MHz}/16 = 250,000$.

Now each is calculated by using $X = (250,000 / \text{Desired Baud Rate}) - 1$

(a) $250,000/9600 - 1 = 26.04 - 1 = 25 = 19$ in hex

(b) $250,000/19200 - 1 = 13.02 - 1 = 12 = 0C$ in hex

(c) $250,000/38400 - 1 = 6.51 - 1 = 5.5 = 5$

(d) $250,000/57600 - 1 = 4.34 - 1 = 3.34 = 3$

48. First we have $16 \text{ MHz}/4 = 4 \text{ MHz}$ and $4 \text{ MHz}/4 = 1 \text{ MHz}$.

Now each is calculated by using $X = (1 \text{ MHz} / \text{Desired Baud Rate}) - 1$:

(a) $1 \text{ MHz}/9600 - 1 = 104.16 - 1 = 103 = 67$ in hex.

(b) $1 \text{ MHz}/19200 - 1 = 52.08 - 1 = 51 = 33$ in hex.

74

(c) $1 \text{ MHz}/38400 - 1 = 26.04 - 1 = 25 = 19$ in hex.

(d) $1 \text{ MHz}/57600 - 1 = 17.36 - 1 = 16 = 10$ in hex.

49. First we have $20 \text{ MHz}/4 = 5 \text{ MHz}$ and $5 \text{ MHz}/16 = 312,500 \text{ Hz}$.

Now each is calculated by using $X = (312500 \text{ Hz} / \text{Desired Baud Rate}) - 1$

(a) $312500 \text{ Hz}/9600 - 1 = 32.55 - 1 = 31 = 1F$ in hex.

(b) $312500 \text{ Hz}/19200 - 1 = 16.27 - 1 = 15 = F$ in hex.

(c) $312500 \text{ Hz}/38400 - 1 = 8.13 - 1 = 7$.

(d) $312500 \text{ Hz}/57600 - 1 = 5.42 - 1 = 4 = 4$

50. First we have $20 \text{ MHz}/4 = 5 \text{ MHz}$ and $5 \text{ MHz}/4 = 1.25 \text{ MHz}$.

Now each is calculated by using $X = (1.25 \text{ MHz} / \text{Desired Baud Rate}) - 1$

- (a) $1.25\text{MHz}/9600 - 1 = 130.2 - 1 = 129 = 81$ in hex.
 (b) $1.25\text{MHz}/19200 - 1 = 65.1 - 1 = 64 = 40$ in hex
 (c) $1.25\text{MHz}/38400 - 1 = 32.55 - 1 = 31 = 1F$ in hex.
 (d) $1.25\text{MHz}/57600 - 1 = 21.7 - 1 = 20.7 = 14$ in hex.
 51. (a) $250,000/9600 - 1 = 26.04 - 1 = 25.04$ and error rate is $(25.04-25)/26 = 0.1 \%$
 (b) $250,000/19200 - 1 = 13.02 - 1 = 12.02$ and error rate is $(12.02 - 12)/13 = 0.1 \%$
 (c) $250,000/38400 - 1 = 6.51 - 1 = 5.5$ and error rate is $(5.5-5)/6 = 8\%$
 (d) $250,000/57600 - 1 = 4.34 - 1 = 3.34$ and error rate is $(3.34 - 3) / 4 = .85\%$
 52. (a) $1\text{MHz}/9600 - 1 = 104.16 - 1 = 103.16$ and error rate is $(103.16 - 103)/104 = 0.15\%$
 (b) $1\text{MHz}/19200 - 1 = 52.08 - 1 = 51.08$ and error rate is $(51.08 - 51)/52 = 0.15\%$
 (c) $1\text{MHz}/38400 - 1 = 26.04 - 1 = 25.04$ and error rate is $(25.04 - 25)/26 = 0.15\%$
 (d) $1\text{MHz}/57600 - 1 = 17.36 - 1 = 16.36$ and error rate is $(16.36 - 16)/17 = 2\%$

SECTION 10.4: PIC18 SERIAL PROGRAMMING IN C

53.

```
void main(void)
{
    TXSTA=0x20; //choose low buad rate,8-BIT
    SPBRG=15; //9600 baud rate/ XTAL=10Mhz
    TXSTAbits.TXEN=1;
    RCSTAbits.SPEN=1;
    while(1)
    {
        TXREG='Z'; //place value in buffer
        while(PIR1bits.TXIF==0); // wait until all gone
    }
}
```

54.

```
void main(void)
{
    unsigned char z;
    unsigned char message[]="The earth is but one country \
    and mankind is citizens";
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 75

```
TXSTA=0x20; //choose low buad rate,8-BIT
SPBRG=2; //57600 baud rate/ XTAL=10Mhz
TXSTAbits.TXEN=1;
RCSTAbits.SPEN=1;
do
{
    for(z=0;z<sizeof(message);z++) //write name
    {
        while(PIR1bits.TXIF==0); //wait for transmit
        TXREG=message[z]; //place char in buffer
    }
}while(1);
}
```

76

CHAPTER 11: INTERRUPT PROGRAMMING IN ASSEMBLY AND C

SECTION 11.1: PIC18 INTERRUPTS

1. interrupt
2. Timer, hardware, serial
3. 0x0008 and 0x0018
4. True
5. 0x0018
6. 0x0008
7. No – All interrupts go to the same location, either low or high.
8. No – All interrupts go to the same location, either low or high.
9. INTCON
10. To bypass the interrupt vector table.
11. GIE is set to 0 so the interrupts are disabled on power up.
12. BSF INTCON, INT0IE
13. BSF INTCON, TMR0IE
14. INTCON
15. 16 bytes (8 words)
16. Unlimited- Since there is no vector entries after it. This is unlike high priority.
17. 16 bytes (8 words)
18. False
19. BCF INTCON, GIE
20. BCF INTCON, INT0IE
21. False
22. 8 bytes (4 words)

SECTION 11.2: PROGRAMMING TIMER INTERRUPTS

23. False
24. No specific address assigned. It can be assigned to low or high priority.
25. BSF INTCON, TMR0IE
26. bit 5, BSF INTCON, TMR0IE
27. When TMR0H rolls over from FFH to 00H, then the interrupt flag is raised and it is directed to the high or low priority vector location to execute the ISR.
28. True
29. When TMR1H:TMR1L rolls from FFFFH to 0000H then Timer1 flag is raised and it is directed to low or high priority vector location to execute the ISR.
30. When TMR1H rolls over from FF to 00
- 31.

ORG 0000H

GOTO MAIN ;bypass interrupt vector table

;-on default all interrupts land at address 00008

ORG 0008H ;interrupt vector table

BTFSS INTCON,TMR0IF ;Timer0 interrupt?

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 77

RETFIE ;No. Then return to main

GOTO T0_ISR ;Yes. Then go Timer0 ISR

;-main program for initialization and keeping CPU busy

ORG 00100H ;after vector table space

```

MAIN
BCF TRISB,7 ;RB7 as an output
CLRF TRISD ;make PORTD output
SETF TRISC ;make PORTC input
MOVLW 0x07 ;Timer0,16-bit,
;no prescale,internal clk
MOVWF T0CON ;load T0CON reg
MOVLW 0xEC ;TMR0H = ECH, the high byte
MOVWF TMR0H ;load Timer0 high byte
MOVLW 0xED ;TMR0L = EDH, the low byte
MOVWF TMR0L ;load Timer0 low byte
BCF INTCON,TMR0IF ;clear timer interrupt flag bit
BSF T0CON,TMR0ON ;start Timer0
BSF INTCON,TMR0IE ;enable Timer 0 interrupt
BSF INTCON,GIE ;enable interrupts globally
;--keeping CPU busy waiting for interrupt
OVER MOVFF PORTC,PORTD ;send data from PORTC to PORTD
BRA OVER ;stay in this loop forever
;-----ISR for Timer 0
T0_ISR
ORG 200H
MOVLW 0xEC ;TMR0H = ECH, the high byte
MOVWF TMR0H ;load Timer0 high byte
MOVLW 0xED ;TMR0L = EDH, the low byte
MOVWF TMR0L ;load Timer0 low byte
BTG PORTB,7 ;toggle RB7
BCF INTCON,TMR0IF ;clear timer interrupt flag bit
EXIT RETFIE ;return from interrupt (See Example 11-2)
END
32.
ORG 0000H
GOTO MAIN ;bypass interrupt vector table
;--on default all interrupts land at address 00008
ORG 0008H ;interrupt vector table
BTFSS PIR1,TMR1IF ;Timer1 interrupt?
RETFIE ;No. Then return to main
GOTO T1_ISR ;Yes. Then go Timer1 ISR
;--main program for initialization and keeping CPU busy
ORG 00100H ;after vector table space
MAIN
BCF TRISB,7 ;RB7 as an output
CLRF TRISD ;make PORTD output
78
SETF TRISC ;make PORTC input
CLRF T1CON ;Timer1,16-bit,
;no prescale,internal clk
MOVLW 0xFE ;TMR1H = FEH, the high byte

```

```

MOVWF TMR1H ;load Timer0 high byte
MOVLW 0x5F ;TMR1L = 5FH, the low byte
MOVWF TMR1L ;load Timer1 low byte
BSF PIE1,TMR1IE ;enable Timer1 interrupt
BCF PIR1,TMR1IF ;clear timer interrupt flag bit
BSF T1CON,TMR1ON ;start Timer1
BSF INTCON,PEIE ;enable peripheral interrupts
BSF INTCON,GIE ;enable interrupts globally
;--keeping CPU busy waiting for interrupt
OVER MOVFF PORTC,PORTD ;send data from PORTC to PORTD
BRA OVER ;stay in this loop forever
;-----ISR for Timer 0
T1_ISR
ORG 200H
MOVLW 0xFE ;TMR1H = FEH, the high byte
MOVWF TMR1H ;load Timer1 high byte
MOVLW 0x5F ;TMR1L = 5FH, the low byte
MOVWF TMR1L ;load Timer1 low byte
BTG PORTB,7 ;toggle RB7
BCF PIR1,TMR1IF ;clear timer interrupt flag bit
EXIT RETFIE
END

```

SECTION 11.3: PROGRAMMING EXTERNAL HARDWARE INTERRUPTS

33. False
 34. 0x0008 if high priority and 0x0018 if low priority, Pins 33, 34, and 35
 35. INTCON, "BSF INTCON, INT0IE"
 36. INTCON3 BSF INTCON3,INT1IE
 37. BSF INTCON, INT0IE
BSF INTCON3,INT1IE
BSF INTCON3,INT2IE
 38. When the input signal goes from high to low the processor finishes executing the current instruction and jumps to ROM location 0x008 to execute the ISR.
 39. False
 40. When the input signal goes from high to low the processor finishes executing the current instruction and jumps to ROM location 0x008 to execute the ISR. The CPU makes GIE = 0, blocking another interrupt from the same source or any other source. At the end of the ISR the RETFIE instruction will make GIE = 1, allowing another interrupt to come from the same source.
 41. INTCON
 42. INTCON3
- Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 79**
43. True
 44. In order to allow the interrupt to come in, INT0IE must be set to high. It is only after INT0IE = 1, that INT0IF being high will cause the CPU to jump to a vector location. INT0IF can become high by external pulse or by an instruction. In some applications to

simulate interrupts we can use an instruction to set INT0IF to cause an interrupt.

45. In order to allow the interrupt to come in, INT1IE must be set to high. It is only after INT1IE = 1, that INT1IF being high will cause the CPU to jump to a vector location.

INT1IF can become high by external pulse or by an instruction. In some applications to simulate interrupts we can use an instruction to set INT1IF to cause an interrupt.

46. When the input signal goes from high to low the processor finishes executing the current

instruction and jumps to ROM location 0x008 to execute the ISR. The CPU makes GIE = 0, blocking another interrupt from the same source or any other source. At the end of the ISR the RETFIE instruction will make GIE = 1, allowing another interrupt to come from the same source.

47. False

48. True

49. Falling is the transition from high to low, Rising is the transition from low to high

50. Clear the appropriate bit in INTCON2 register

51. True

52. INTCON2 register.

SECTION 11.4: PROGRAMMING THE SERIAL COMMUNICATION

INTERRUPT AND

SECTION 11.5: PORTB-CHANGE INTERRUPT

53. True

54. 0x0008, 16 bytes

55. PIR1, BSF PIE1, TXIE

56. When TXIE = 1, upon transferring the last bit of the byte out of TXREG, TXIF is raised.

When TXIF is raised the code gets interrupted and jumps to the ISR to get another byte to be written to the TXREG.

57. True

58. False, TXIF is cleared automatically by the CPU upon writing to TXREG.

59. RCIF is cleared automatically by the CPU upon reading a byte from RCREG.

60. The code executing is interrupted and the CPU jumps to the ISR to write another byte to

TXREG.

61. The code executing is interrupted and the CPU jumps to the ISR to read the received byte from RCREG.

62.

```
ORG 0000H
```

```
GOTO MAIN ;bypass interrupt vector table
```

```
;-on default all interrupts go to to address 00008
```

```
ORG 0008H ;interrupt vector table
```

```
BTFSC PIR1,RCIF ;Is interrupt due to transmit?
```

```
BRA RC_ISR ;Yes. Then go to ISR
```

```
RETFIE ;No. Then return
```

```
ORG 0040H
```

```
80
```

```
RC_ISR ;service routine for RCIF
```

```
MOVFF RCREG,PORTD ;get new value, clear RCIF
```

```

    RETFIE ;then return to main
    ;--the main program for initialization
    ORG 00100H
    MAIN
    CLRF TRISD ;make PORTD output
    BSF TRISB,4 ;make RB4 an input
    BCF TRISC,7 ;make RC7 an output
    MOVLW 0x90 ;enable receive and choose
    ;low baud
    MOVWF RCSTA ;write to reg
    MOVLW D'15' ;9600 bps
    ;(Fosc / (64 * Speed) - 1)
    MOVWF SPBRG ;write to reg
    BSF TRISC, RX ;make RX pin of PORTC an
    ;input pin
    BSF RCSTA, SPEN ;enable the serial port
    BSF PIE1,RCIE ;enable TX interrupt
    BSF INTCON,PEIE ;enable peripheral interrupts
    BSF INTCON,GIE ;enable interrupts globally
    AGAIN
    BTFSS PORTB,4 ;bit test RB4
    GOTO OVER
    BSF PORTC, 7 ;set RC7
    GOTO AGAIN
    OVER
    BCF PORTC, 7 ;clear RC7
    GOTO AGAIN ;stay in this loop forever
    END

```

63. a. RBIF

b. INTCON

c. For PORTB-change, there is only a single flag associated with it and it is triggered on positive and negative edges.

d. Pins 37 (RB4), 38 (RB5), 39 (RB6), and 40 (RB7)

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 81

SECTION 11.6: INTERRUPT PRIORITY IN THE PIC18

64. True

65. IPEN of RCON register. Setting IPEN = 1 allows the interrupts to jump to 0x0008 or 0x0018 depending on individual xIP (priority) bits.

66. INT0 is always high priority. This is the only interrupt that does not have the option of changing the priority.

67. IPR1, BCF IPR1, TMR1IP

68. INTCON3, BCF INTCON3, INT1IP

69. It depends on the order that INT1IF and INT2IF are checked in the ISR located at 0x0018. The first one checked will be serviced first.

70. It depends on the order that TMR0IF and TMR1IF are checked in the ISR located at 0x0018. The first one checked will be serviced first.

71. It depends on the order that TMR0IF and TMR1IF are checked in the ISR located at 0x0008. The first one checked will be serviced first.
72. It depends on the order that INT1IF and INT2IF are checked in the ISR located at 0x0008. The first one checked will be serviced first.
73. The high priority ISR will be finished first, before it goes to the low priority ISR.
74. The low priority ISR will be interrupted by the high priority interrupt and the CPU will jump to the high priority ISR. Only after finishing the high priority ISR, that the CPU will finish executing the low priority ISR.
75. The GIEH will disable the high priority interrupts.
76. False
77. The GIEL will disable the low priority interrupts
78. The RETFIE at the end will enable the GIEL automatically which allows the low interrupts to come in again.
79. RETFIE 1 restores all shadow registers, WREG, BSR, and STATUS
80. Fast context allows the processor to save the three key registers WREG, BSR, and STATUS instead of saving them individually. This only works with high priority interrupts.

82

CHAPTER 12: LCD AND KEYBOARD INTERFACING

SECTION 12.1: LCD INTERFACING

1. 8
2. They are the control lines for the LCD. E is for latching information into the LCD, R/W is for reading from or writing information into the LCD , and RS is for making a distinction between the data and command.
3. Vee controls the contrast of the screen while Vcc provides power to the LCD.
4. command, 01h
5. 0Fh
6. RS = 0, RW = 0, E = H-to-L pulse
7. RS = 1, RW = 0, E = H-to-L pulse
8. (a)
9. True
10. Sending information to the LCD without checking the busy flag is very simple to write but the microcontroller wastes a lot of time in a delay subroutine. The advantage of monitoring the busy flag is that the next information is sent when the LCD is ready and there is no wasting of time. This is very critical, especially when the microcontroller is busy and must serve many devices. However, the subroutine for monitoring the busy flag is much harder to write and takes more code. To monitor the busy flag, we make the port D0 - D7 of the LCD an input port, read the D7 bit, and wait for low.
11. 80h is the starting location ,and 16 locations to the right is 8Fh.
12. From Table 12-3 we have C0h, which is first location of line 2.
13. 80h is the starting location, and 20 locations to the right is 13h which result in 80h + 13h = 93h.

14. This is 2 locations from C0h since C0 is the first location of line 2.
15. If 80h is the address of the first location, then adding 39 (27h) we get 80h + 27h = A7h.
16. If C0h is the address of the first location, then adding 39 (27h) we get C0h + 27h = E7h.
17. 89h since 80h + 9 = 89h. The 10th is address 9 since it starts at 0.
18. C0h + 13h = D3h. Notice that the 20th starts at 0 and goes to 13h.
- 19.

```

LCD_DATA EQU PORTD ;LCD data pins RD0-RD7
LCD_CTRL EQU PORTC ;LCD control pins
RS EQU RC4 ;RS pin of LCD
RW EQU RC5 ;R/W pin of LCD
EN EQU RC6 ;E pin of LCD
CLRF TRISD ;PORTD = Output
CLRF TRISC ;PORTC = Output
BCF LCD_CTRL,EN ;enable idle low
CALL LDELAY ;wait for initialization
MOVLW 0x38 ;init. LCD 2 lines, 5x7 matrix
CALL COMNWRT ;call command subroutine
CALL LDELAY ;initialization hold
MOVLW 0x0E ;display on, cursor on
CALL COMNWRT ;call command subroutine

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 83

```

CALL DELAY ;give LCD some time
MOVLW 0x01 ;clear LCD
CALL COMNWRT ;call command subroutine
CALL DELAY ;give LCD some time
MOVLW 0x06 ;shift cursor right
CALL COMNWRT ;call command subroutine
CALL DELAY ;give LCD some time
MOVLW 0x84 ;cursor at line 1, pos. 4
CALL COMNWRT ;call command subroutine
CALL DELAY ;give LCD some time
MOVLW A'N' ;display letter 'N'
CALL DATAWRT ;call display subroutine
CALL DELAY ;give LCD some time
MOVLW A'O' ;display letter 'O'
CALL DATAWRT ;call display subroutine
AGAIN BTG LCD_CTRL,0
BRA AGAIN ;stay here
COMNWRT ;send command to LCD
MOVWF LCD_DATA ;copy WREG to LCD DATA pin
BCF LCD_CTRL,RS ;RS = 0 for command
BCF LCD_CTRL,RW ;R/W = 0 for write
BSF LCD_CTRL,EN ;E = 1 for high pulse
CALL SDELAY ;make a wide En pulse
BCF LCD_CTRL,EN ;E = 0 for H-to-L pulse

```

```

RETURN
DATAWRT ;write data to LCD
MOVWF LCD_DATA ;copy WREG to LCD DATA pin
BSF LCD_CTRL,RS ;RS = 1 for data
BCF LCD_CTRL,RW ;R/W = 0 for write
BSF LCD_CTRL,EN ;E = 1 for high pulse
CALL SDELAY ;make a wide En pulse
BCF LCD_CTRL,EN ;E = 0 for H-to-L pulse
RETURN
;look in previous chapters for delay routines
END
20.
;PORTD = D0-D7, RC4 = RS, RC5 = R/W, RC6 = E pins
LCD_DATA EQU PORTD ;LCD data pins RD0-RD7
LCD_CTRL EQU PORTC ;LCD control pins
RS EQU RC4 ;RS pin of LCD
RW EQU RC5 ;R/W pin of LCD
EN EQU RC6 ;E pin of LCD
CLRF TRISD ;PORTD = Output
CLRF TRISC ;PORTC = Output
BCF LCD_CTRL,EN ;enable idle low
CALL LDELAY ;long delay (250 ms) for power-up
MOVLW upper(MYCOM)
84
MOVWF TBLPTRU
MOVLW high(MYCOM)
MOVWF TBLPTRH
MOVLW low(MYCOM)
MOVWF TBLPTRL
C1 TBLRD*+
MOVF TABLAT,W ;give it to WREG
IORLW 0x0 ;Is it the end of command?
BZ SEND_DAT ;if yes then go to display data
CALL COMNWRT ;call command subroutine
CALL DELAY ;give LCD some time
BRA C1
SEND_DAT MOVLW upper(MYDATA)
MOVWF TBLPTRU
MOVLW high(MYDATA)
MOVWF TBLPTRH
MOVLW low(MYDATA)
MOVWF TBLPTRL
DT1 TBLRD*+
MOVF TABLAT,W ;give it to WREG
IORLW 0x0 ;Is it the end of data string?
BZ OVER ;if yes then exit
CALL DATAWRT ;call DATA subroutine

```

```

CALL DELAY ;give LCD some time
BRA DT1
OVER BRA OVER ;stay here
COMNWRT ;send command to LCD
MOVWF LCD_DATA ;copy WREG to LCD DATA pin
BCF LCD_CTRL,RS ;RS = 0 for command
BCF LCD_CTRL,RW ;R/W = 0 for write
BSF LCD_CTRL,EN ;E = 1 for high pulse
CALL SDELAY ;make a wide En pulse
BCF LCD_CTRL,EN ;E = 0 for H-to-L pulse
RETURN
DATAWRT ;write data to LCD
MOVWF LCD_DATA ;copy WREG to LCD DATA pin
BSF LCD_CTRL,RS ;RS = 1 for data
BCF LCD_CTRL,RW ;R/W = 0 for write
BSF LCD_CTRL,EN ;E = 1 for high pulse
CALL SDELAY ;make a wide En pulse
BCF LCD_CTRL,EN ;E = 0 for H-to-L pulse
RETURN
ORG 500H
MYCOM DB 0x38,0x0E,0x01,0x06,0x84,0 ;commands and null
MYDATA DB "HELLO",0 ;data and null
;look in Chapter 3 for delay routines
END

```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 85
SECTION 12.2: KEYBOARD INTERFACING

21. 1s
22. (a)
23. (b)
24. key 3
25. This allows the microcontroller to do other things.
26. Use a chip for the keyboard (for both key press and identification) and then pass the scan code for the pressed key to the microcontroller via a hardware interrupt.

86

CHAPTER 13: ADC, DAC, AND SENSOR INTERFACING
SECTION 13.1: ADC CHARACTERISTICS

1. True
2. True
3. True
4. False
5. True
6. True
7. False
8. True
9. False
10. False

11. (d)
12. (d)
13. (a) $(5V) / (2^8) = 19.53 \text{ mV}$
 (b) $(5V) / (2^{10}) = 4.88 \text{ mV}$
 (c) $(5V) / (2^{12}) = 1.22 \text{ mV}$
 (d) $(5V) / (2^{16}) = 76.29 \mu V$
14. (a) since the step size is 5 mV and all inputs are high, we get $255 \times 5 \text{ mV} = 1.275 \text{ V}$.
 (b) $10011001 = 153$ and $153 \times 5 \text{ mV} = 0.756 \text{ V}$.
 (c) $1101100 = 108$ and $108 \times 5 \text{ mV} = 0.540 \text{ V}$.
15. 1.28 V since $256 \times 5 \text{ mV} = 1.28 \text{ V}$
16. (a) since the step size is 10 mV and all inputs are high, we get $255 \times 10 \text{ mV} = 2.56 \text{ V}$.
 (b) $10011001 = 153$ and $153 \times 10 \text{ mV} = 1.53 \text{ V}$.
 (c) $1101100 = 108$ and $108 \times 10 \text{ mV} = 1.08 \text{ V}$.

SECTION 13.2: ADC PROGRAMMING IN PIC18

17. True
 18. False. It is 10-bit
 19. True
 20. True
 21. True
 22. False
 23. False
 24. True
 25. False
 26. True
 27. It is kept by the registers ADRESL and ADRESH. At the end of conversion the DONE flag goes low.
 28. The old data gets lost.
 29. (a) $1.024V / 1024 = 1 \text{ mV}$
 (b) $2.048 / 1024 = 2 \text{ mV}$
 (c) $2.56 / 1024 = 2.5 \text{ mV}$
- Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 87**
30. $2 \text{ mV} \times 1024 = 2048 \text{ mV} = 2.048 \text{ V}$
 31. $3 \text{ mV} \times 1024 = 3.072 \text{ V}$
 32. $1 \text{ mV} \times 1023 = 1.023 \text{ V}$
 33. Step Size = $1.024 / 1024 = 1 \text{ mV}$
 (a) $255 \times 1 \text{ mV} = 0.255 \text{ V}$
 (b) $152 \times 1 \text{ mV} = 0.152 \text{ V}$
 (c) $208 \times 1 \text{ mV} = 0.208 \text{ V}$
 34. $4 \text{ mV} \times 1024 = 4096 \text{ mV} = 4.096 \text{ V}$
 35. Step Size = $2.56 / 1024 = 2.5 \text{ mV}$
 (a) $1023 \times 2.5 \text{ mV} = 2.5575 \text{ V}$
 (b) $513 \times 2.5 \text{ mV} = 1.2825 \text{ V}$
 (c) $816 \times 2.5 \text{ mV} = 2.04 \text{ V}$
 36. (a) $8\text{MHz}/2 = 4\text{MHz}$, $T_{ad} = 1/4\text{MHz} = 250\text{ns}$, Invalid since it is faster than $1.6\mu\text{s}$
 (b) $8\text{MHz}/4 = 2\text{MHz}$, $T_{ad} = 1/2\text{MHz} = 500\text{ns}$, Invalid since it is faster than $1.6\mu\text{s}$

- (c) $8\text{MHz}/8 = 1\text{MHz}$, $T_{\text{ad}} = 1/1\text{MHz} = 1\mu\text{s}$, Invalid since it is faster than $1.6\mu\text{s}$
 (d) $8\text{MHz}/16 = 500\text{KHz}$, $T_{\text{ad}} = 1/500\text{KHz} = 2\mu\text{s}$ and conversion time is $12 \times 2\mu\text{s} = 24\mu\text{s}$.
 (e) $8\text{MHz}/32 = 250\text{KHz}$, $T_{\text{ad}} = 1/250\text{KHz} = 4\mu\text{s}$ and conversion time is $12 \times 4\mu\text{s} = 48\mu\text{s}$
 37. (a) $12\text{MHz}/8 = 1.5\text{MHz}$, $T_{\text{ad}} = 1/1.5\text{MHz} = 667\text{ns}$, Invalid since it is faster $1.6\mu\text{s}$.
 (d) $12\text{MHz}/16 = 750\text{KHz}$, $T_{\text{ad}} = 1/750\text{KHz} = 1.33\mu\text{s}$, Invalid since it is faster $1.6\mu\text{s}$.
 (e) $12\text{MHz}/32 = 375\text{KHz}$, $T_{\text{ad}} = 1/375\text{KHz} = 2.67\mu\text{s}$ and conversion time is $12 \times 2.67\mu\text{s} = 32.04\mu\text{s}$
 (e) $12\text{MHz}/64 = 187.5\text{KHz}$, $T_{\text{ad}} = 1/187.5\text{KHz} = 5.3\mu\text{s}$ and conversion time is $12 \times 5.3\mu\text{s} = 63.6\mu\text{s}$
 38. By the instruction "BSF ADCON0,GO"
 39. By monitoring the GO bit of ADCON0 register.
 40. One or none at all.
 41. PORTA.
 42. ADCON1
 43. ADCON0
 44. ADCON0
 45. $01000001 = 41\text{H}$
 46. $11000100 = \text{C4H}$
 47. $00010000 = 10\text{H}$
 48. $00000101 = 05\text{H}$
 49. ADIF bit belongs to PIR1 register and ADIE belongs to PIE1 register
 50. High

SECTION 13.3: DAC INTERFACING

51. True.
 52. (a) 256 (b) 1024 (c) 4096
 53. $2\text{ma} * (255/256) = 1.99\text{ma}$
 54. (a) 1.195mA since $10011001\text{B} = 153$ and $(153 \times 2\text{mA})/256 = 1.195\text{mA}$
 (b) 1.594mA since $11001100\text{B} = 204$ and $(204 \times 2\text{mA})/256 = 1.594\text{mA}$
 (c) 1.859mA since $11101110\text{B} = 238$ and $(238 \times 2\text{mA})/256 = 1.859\text{mA}$
88
 (d) 0.2656mA
 (e) 0.0703125mA
 (f) 1.063mA

55. More

56. All high

SECTION 13.4: SENSOR INTERFACING AND SIGNAL CONDITIONING

57. The output corresponds with the input linearly.
 58. 10mV
 59. Adjusting the output of a given sensor (device) to meet the needs of the ADC chip
 60. To maintain constant voltage so that the variation of V_{CC} source has no effect on the V_{ref} voltage. This must be done since the source voltage for V_{ref} is V_{CC} .

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 89

CHAPTER 14: USING FLASH AND EEPROM MEMORIES FOR DATA STORAGE

SECTION 14.1: SEMICONDUCTOR MEMORY

1. The storage of the chip is measured in Megabits while the Computer memory is measured in Megabytes.
2. True, the more address lines the more memory locations.
3. True, the memory location size is fixed.
4. True, the more data lines the more memory locations
5. True
6. access time
7. True
8. electrically erasable
9. True
10. DRAM
11. SRAM
12. DRAM and SRAM
13. (c)
14. (c)
15. (a) 32Kx8, 256K (f) 8Kx1, 8K
(b) 8Kx8, 64K (g) 4Kx8, 32K
(c) 4Kx8, 32K (h) 2Kx8, 16K
(d) 8Kx8, 64K (i) 256Kx4, 1M
(e) 4Mx1, 4M (j) 64Kx8, 512K
16. (a) 128K 14 8 (f) 256K 8 4
(b) 256K 15 8 (g) 8M 20 8
(c) 512K 16 8 (h) 16M 11 4
(d) 2M 18 8 (i) 512K 16 8
(e) 512K 16 8

SECTION 14.2: ERASING AND WRITING TO FLASH IN THE PIC18F

17. True
18. True
19. True
20. True
21. False
22. False. It can be erased in blocks of 64 bytes, but when we write, it must be in block of 8 bytes.
23. False
24. False
25. TBLPTR and TABLAT
26. TBLPTR, TABLAT, EECON1, and EECON2
27. TBLPTR, EECON1, and EECON2
28. WREN bit is used by the programmer to enable writing to Flash and EEPROM. The WR is used by the PIC18 to indicate that write cycle is finished.
29. TBLPTR and TABLAT
- 90**
30. TBLPTR, TABLAT, EECON1, and EECON2

31. In the short write the data is stored in the buffer called TABLAT, while in the long write

the data is actually written(burned) into the Flash.

32. During the long write

33. 8 bytes

34. 64 bytes

35. (a) and (e)

36. (a), (c), (e), and (g)

37. 2000H, 2008H, 2010H, 2018H

38. 2000H, 2040H, 2080H, 20C0H

39.

```
MOVLW upper(MYDATA)
```

```
MOVWF TBLPTRU ;load the upper address
```

```
MOVLW high(MYDATA)
```

```
MOVWF TBLPTRH ;load the high byte of address
```

```
MOVLW low(MYDATA)
```

```
MOVWF TBLPTRL ;load the low byte of address
```

```
BSF EECON1,EEPGD ;point to Flash memory
```

```
BCF EECON1,CFGS ;access Flash program
```

```
BSF EECON1,WREN ;enable write
```

```
BSF EECON1, FREE ;enable row erase operation
```

```
BCF INTCON,GIE ;disable all interrupts
```

```
MOVLW 55H ;wreg = 55h
```

```
MOVWF EECON2 ;write to dummy reg
```

```
MOVLW 0AAH ;wreg = aah
```

```
MOVWF EECON2 ;write to dummy reg
```

```
BSF EECON1,WR ;now write it to Flash
```

```
NOP ;wait
```

```
BSF INTCON,GIE ;enable all interrupts
```

```
BCF EECON1,WREN ;disable write to memory
```

```
MOVLW upper(MYDATA)
```

```
MOVWF TBLPTRU ;load the upper address
```

```
MOVLW high(MYDATA)
```

```
MOVWF TBLPTRH ;load the high byte of address
```

```
MOVLW low(MYDATA)
```

```
MOVWF TBLPTRL ;load the low byte of address
```

```
;start a short write
```

```
MOVLW A'H' ;load the byte into WREG
```

```
MOVWF TABLAT ;move it to TABLATch reg
```

```
TBLWT*+ ;perform short write and increment
```

```
MOVLW A'E' ;load the byte into WREG
```

```
MOVWF TABLAT ;move it to TABLATch reg
```

```
TBLWT*+ ;perform short write and increment
```

```
MOVLW A'L' ;load the byte into WREG
```

```
MOVWF TABLAT ;move it to TABLATch reg
```

```
TBLWT*+ ;perform short write
```

```
MOVLW A'L' ;load the byte into WREG
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 91

```
MOVWF TABLAT ;move it to TABLATch reg
TBLWT*+ ;perform short write
MOVLW A'0' ;load the byte into WREG
MOVWF TABLAT ;move it to TABLATch reg
TBLWT*+ ;perform short write
BSF EECON1,EEPGD ;point to Flash memory
BCF EECON1,CFGs ;
BSF EECON1,WREN ;enable write
BCF INTCON,GIE ;disable all interrupts
MOVLW 55H ;wreg = 55h
MOVWF EECON2 ;write to dummy reg
MOVLW 0AAH ;wreg = aah
MOVWF EECON2 ;write to dummy reg
BSF EECON1,WR ;now write it to Flash
NOP ;wait
BSF INTCON,GIE ;enable all interrupts
BCF EECON1,WREN ;disable write to memory
GOTO $ ;stay here
ORG 2000H
MYDATA data "ERASE ME"
END
```

40. Add the following to the end of Problem 39.

```
MOVLW 0x20 ;enable transmit and low baud rate
MOVWF TXSTA ;write to reg
BCF PIR1,TXIF
MOVLW D'15' ;9600 bps (Fosc/(64*Speed)-1)
MOVWF SPBRG ;write to reg
BCF TRISC, TX ;make TX pin of PORTC an output
BSF RCSTA, SPEN ;enable the entire serial port
MOVLW 5 ;number of bytes in RAM
MOVWF COUNT
MOVLW upper (MYDATA);load TBLPTR
MOVWF TBLPTRU
MOVLW high (MYDATA)
MOVWF TBLPTRH
MOVLW low (MYDATA)
MOVWF TBLPTRL
LN TBLRD*+ ;read the character
MOVF TABLAT,W
OVER BTFSS PIR1, TXIF ;wait to send character
BRA OVER
MOVWF TXREG ;send character to serial port
DECFSZ COUNT,F ;loop until buffers are full
BRA LN ;repeat
END
```

SECTION 14.3: READING AND WRITING OF DATA EEPROM IN PIC18F

- 41. False
- 42. True
- 43. False
- 44. True
- 45. True
- 46. False.
- 47. False, there is no erase function. The write is a replace function.
- 48. False
- 49. True
- 50. EEADR, EEDATA, and EECON1
- 51. EEADR, EEDATA, EECON1, and EECON2
- 52. Flash can be used for both code (program) and data, while the EEPROM is used for data storage only. Writing to Flash is in block size, while writing to EEPROM is byte size
- 53. one byte
- 54. EEPGD, CFGS, and RD
- 55. To prevent interruption during the long write which can take up 2 msec.
- 56. Since reading the byte from Flash and EEPROM take only 2 machine cycle, there is no need to disable the interrupts. This is unlike the long write cycle time, which takes up to 2 msec

57.

```
MOVLW 0x0 ;starts at location 0H of EEPROM
MOVWF EEADR ;load the EEPROM address
MOVLW A'H' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'E' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'L' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'L' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'O' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A' ' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 93

```
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'W' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'O' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'R' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'L' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
MOVLW A'D' ;load the byte into WREG
MOVWF EEDATA ;move it to EEDATA reg
CALL EE_WRT
INCF EEADR,F ;point to next location
HERE BRA HERE
EE_WRT
BCF EECON1,EEPGD ;point to EEPROM memory
BCF EECON1,CFG5 ;
BSF EECON1,WREN ;enable write
BCF INTCON,GIE ;disable all interrupts
MOVLW 0x55 ;wreg = 55h
MOVWF EECON2 ;write to dummy reg
MOVLW 0xAA ;wreg = aah
MOVWF EECON2 ;write to dummy reg
BSF EECON1,WR ;now write it to Flash
BSF INTCON,GIE ;enable all interrupts
EE_WAIT BTFSS PIR2,EEIF
BRA EE_WAIT
BCF PIR2,EEIF
RETURN
END
```

58. Add the following to the end of Problem 57.

```
MOVLW 0x20 ;enable transmit and low baud rate
MOVWF TXSTA ;write to reg
BCF PIR1,TXIF
MOVLW D'15' ;9600 bps (Fosc/(64*Speed)-1)
MOVWF SPBRG ;write to reg
BCF TRISC, TX ;make TX pin of PORTC an output
```

94

```
BSF RCSTA, SPEN ;enable the entire serial port
MOVLW 0x0 ;starts at location 0H of EEPROM
MOVWF EEADR ;load the EEPROM address
BCF EECON1,EEPGD ;point to EEPROM memory
BCF EECON1,CFG1 ;
MOVLW D'11' ;count = 11
MOVWF COUNT
OVER BSF EECON1,RD ;enable read
NOP
R1 BTFSS PIR1, TXIF
BRA R1
MOVWF EEDATA,TXREG ;read the data to serial port
INCF EEADR,F ;point to next location
DECF COUNT,F ;decrement counter
BNZ OVER ;keep repeating
HERE BRA HERE
END
```

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 95

CHAPTER 15: CCP AND ECCP PROGRAMMING

SECTION 15.1: STANDARD AND ENHANCED CCP MODULES

1. True
2. True
3. True
4. True
5. True
6. 2
7. Pin 17

SECTION 15.2: COMPARE MODE PROGRAMMING

8. True
9. False
10. True
11. Timer1 and/or Timer3
12. When the TMR1H:TMR1L equals CCPR1H:CCPR1L.
13. PIR1
14. 0x08
15. 0x09
16. 0x02
- 17.

```
MOVLW 0x02
MOVWF CCP1CON ;Compare mode, toggle upon match
CLRF T3CON ;Timer1 for Compare
CLRF T1CON ;Timer 1, internal clock, 1:1
prescaler
BCF TRISC,CCP1 ;CCP1 pin as output
BSF TRISC,T1CKI ;T1CLK pin as input pin
MOVLW D'10'
```

```

MOVWF CCPR1L ;CCPR1L = 10
MOVLW 0x0 ;CCPR1H = 0
MOVWF CCPR1H
OVER CLRF TMR1H ;clear TMR1H
CLRF TMR1L ;clear TMR1L
BCF PIR1,CCP1IF ;clear CCP1IF
BSF T1CON,TMR1ON ;start Timer1
B1 BTFSS PIR1,CCP1IF
BRA B1
;-----CCP toggle CCP pin upon match
B2 BCF T1CON,TMR1ON ;stop Timer1
GOTO OVER ;keep doing it
96
18.
MOVLW 0x02
MOVWF CCP1CON ;Compare mode, toggle upon match
MOVLW 0x42
MOVWF T3CON ;Timer3 for Compare, 1:1 prescaler
BCF TRISC,CCP1 ;CCP1 pin as output
BSF TRISC,T1CKI ;T3CLK pin as input pin
MOVLW 0xE8
MOVWF CCPR1L ;CCPR1L = E8 (3E8 = 1000)
MOVLW 0x03 ;CCPR1H = 3
MOVWF CCPR1H
OVER CLRF TMR3H ;clear TMR3H
CLRF TMR3L ;clear TMR3L
BCF PIR1,CCP1IF ;clear CCP1IF
BSF T3CON,TMR3ON ;start Timer3
B1 BTFSS PIR1,CCP1IF
BRA B1
;-----CCP toggle CCP pin upon match
B2 BCF T3CON,TMR3ON ;stop Timer3
GOTO OVER ;keep doing it
MOVLW 0x02
MOVWF CCP1CON ;Compare mode, toggle upon match
MOVLW 0x42
MOVWF T3CON;use Timer3 for Compare mode, 1:1 Prescaler
BCF TRISC,CCP1 ;CCP1 pin as output
MOVLW 0xC3
MOVWF CCPR1H ;CCPR1H = 0xC3
MOVLW 0x50
MOVWF CCPR1L ;CCPR1L = 0x50
OVER CLRF TMR3H ;clear TMR3H
CLRF TMR3L ;clear TMR3L
BCF PIR1,CCP1IF ;clear CCP1IF
BSF T3CON,TMR3ON ;start Timer3
B1 BTFSS PIR1,CCP1IF

```

```

BRA B1
;CCP toggles CCP1 pin upon match
BCF T3CON,TMR3ON ;stop Timer3
GOTO OVER ;keep doing it
19.
MOVLW 0x02
MOVWF CCP1CON ;Compare mode, toggle upon match
MOVLW 0x0
MOVWF T3CON ;use Timer1 for Compare mode
MOVLW 0x0
MOVWF T1CON ;Timer1, internal CLK, 1:1 prescale
BCF TRISC,CCP1 ;CCP1 pin as output
Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 97
MOVLW 0x30
MOVWF CCPR1H ;CCPR1H = 0x30
MOVLW 0xD4
MOVWF CCPR1L ;CCPR1L = 0xD4
OVER CLRF TMR1H ;clear TMR1H
CLRF TMR1L ;clear TMR1L
BCF PIR1,CCP1IF ;clear CCP1IF
BSF T1CON,TMR1ON ;start Timer1
B1 BTFSS PIR1,CCP1IF
BRA B1
;CCP toggles CCP1 pin upon match
BCF T1CON,TMR1ON ;stop Timer1
GOTO OVER ;keep doing it

```

SECTION 15.3: CAPTURE MODE PROGRAMMING

```

20. True
21. False
22. False
23. Timer1 and/or Timer3
24. 0x04
25. 0x06
26. 0x00
27. MOVLW 0x05
MOVWF CCP1CON ;Capture mode risingedge
MOVLW 0x42
MOVWF T3CON ;Timer1 for Capture,
CLRF TRISB ;make PORTB output port
CLRF TRISD ;make PORTD output port
BSF TRISC,CCP1 ;make CCP1 pin an input
MOVLW 0x0
MOVWF CCPR1H ;CCPR1H = 0
MOVWF CCPR1L ;CCPR1L = 0
OVER CLRF TMR3H ;clear TMR3H
CLRF TMR3L ;clear TMR3L
BCF PIR1,CCP1IF ;clear CCP1IF

```

```

RE_1 BTFSS PIR1, CCP1IF
BRA RE_1 ;stay here for 1st rising edge
BSF T3CON, TMR3ON ;start Timer3
BCF PIR1, CCP1IF ;clear CCP1IF for next
RE_2 BTFSS PIR1, CCP1IF
BRA RE_2 ;stay here for 2nd rising edge
BCF T3CON, TMR3ON ;stop Timer3
MOVFF TMR3L, PORTB ;put low byte on PORTB
MOVFF TMR3H, PORTD ;put high byte on PORTD
GOTO OVER ;keep doing it

```

98

SECTION 15.4: PWM PROGRAMMING

28. True
29. False
30. True
31. Timer2
32. 0x0C
33. CCPR1L
34. CCP1CON
35. Sets the decimal point portion of the duty cycle
36. 11
37. Fractional
38. Using the $PR2 = F_{osc} / (4 * F_{pwm} * N)$ equation, we must set $N = 8$ for prescale. Therefore, we have
 $PR2 = [(10 \text{ MHz} / (4 * 2 \text{ kHz} * 8))] - 1 = 156 - 1 = 155$ and because
 $155 * 25\% = 38.75$ we have $CCPR1L = 38$ and $DC1B2:DC1B1 = 11$ for the 0.75 portion.
39. Using the $PR2 = F_{osc} / (4 * F_{pwm} * N)$ equation, we must set $N = 8$ for prescale. Therefore, we have
 $PR2 = [(10 \text{ MHz} / (4 * 1.8 \text{ kHz} * 8))] - 1 = 174 - 1 = 173$ and because
 $173 * 25\% = 43.25$ we have $CCPR1L = 43$ and $DC1B2:DC1B1 = 01$ for the 0.25 portion.
40. Using the $PR2 = F_{osc} / (4 * F_{pwm} * N)$ equation, we must set $N = 8$ for prescale. Therefore, we have
 $PR2 = [(10 \text{ MHz} / (4 * 1.5 \text{ kHz} * 8))] - 1 = 208 - 1 = 207$ and because
 $207 * 25\% = 51.75$ we have $CCPR1L = 51$ and $DC1B2:DC1B1 = 11$ for the 0.75 portion.
41. Using the $PR2 = F_{osc} / (4 * F_{pwm} * N)$ equation, we must set $N = 16$ for prescale. Therefore, we have
 $PR2 = [(10 \text{ MHz} / (4 * 1.2 \text{ kHz} * 16))] - 1 = 130 - 1 = 129$ and because
 $129 * 25\% = 32.25$ we have $CCPR1L = 32$ and $DC1B2:DC1B1 = 01$ for the 0.25 portion.

SECTION 15.5: ECCP PROGRAMMING

42. True
43. False
44. False
45. Timer2

46. PIR2
47. 0x0A
48. Pin 27
49. Timer1 or Timer3
50. Pins 27, 28, 29, 30
51. 0x08

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 99

52. 0x4D
53. EDC1B1:EDC1B0
54. ECCP1CON
55. Sets the least significant bits, which are the decimal portion.
56. 10
57. fractional
58. Using the $PR2 = F_{osc} / (4 * F_{pwm} * N)$ equation, we must set $N = 8$ for prescale. Therefore, we have
 $PR2 = [(10 \text{ MHz} / (4 * 2 \text{ kHz} * 8))] - 1 = 156 - 1 = 155$ and because
 $155 * 25\% = 38.75$ we have $ECCPR1L = 38$ and $EDC1B2:EDC1B1 = 11$ for the 0.75 portion.
59. Using the $PR2 = F_{osc} / (4 * F_{pwm} * N)$ equation, we must set $N = 8$ for prescale. Therefore, we have
 $PR2 = [(10 \text{ MHz} / (4 * 1.8 \text{ kHz} * 8))] - 1 = 174 - 1 = 173$ and because
 $173 * 25\% = 43.25$ we have $ECCPR1L = 43$ and $EDC1B2:EDC1B1 = 01$ for the 0.25 portion.
60. Using the $PR2 = F_{osc} / (4 * F_{pwm} * N)$ equation, we must set $N = 8$ for prescale. Therefore, we have
 $PR2 = [(10 \text{ MHz} / (4 * 1.5 \text{ kHz} * 8))] - 1 = 208 - 1 = 207$ and because
 $207 * 25\% = 51.75$ we have $ECCPR1L = 51$ and $EDC1B2:EDC1B1 = 11$ for the 0.75 portion.
61. Using the $PR2 = F_{osc} / (4 * F_{pwm} * N)$ equation, we must set $N = 16$ for prescale. Therefore, we have
 $PR2 = [(10 \text{ MHz} / (4 * 1.2 \text{ kHz} * 16))] - 1 = 130 - 1 = 129$ and because
 $129 * 25\% = 32.25$ we have $ECCPR1L = 32$ and $EDC1B2:EDC1B1 = 01$ for the 0.25 portion.

100

CHAPTER 16: SPI PROTOCOL AND DS1306 RTC INTERFACING
SECTION 16.1: SPI BUS PROTOCOL

1. True
2. False
3. True
4. False
5. True
6. True
7. True
8. False
9. SDI and SDO are tied together
10. D7 is high for a write, D7 is low for a read

SECTION 16.2: DS1306 RTC INTERFACING AND PROGRAMMING

11. 16
12. Pin 16
13. 2
14. True
15. True
16. 2099
17. SDI is used to bring data into the SPI device. SDO is used to send data out of the SPI device. SCL is used to synchronize data transfer between the SPI device and microcontroller.
18. input
19. low, high
20. Vbat, if it is connected to an external source, otherwise it is lost.
21. Voltage Battery backup, input
22. Gnd
23. Input, Vcc
24. Input, +5
25. Output
26. Output
27. Output
28. Output
29. 128, Read 00-7F, Write 80-FF
30. Undefined if all power is lost. If secondary source is available, it will retain the data.
31. It will retain the last value, since only the general purpose RAM is nonvolatile.
32. When Vcc1 drops below Vbat
33. 0x00-0x02
34. 0x03-0x06
35. 0x82, bit 5
36. 0x82, bit 6

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 101

37. 0x06
38. 0x7F
39. True
40.

```
BSF PORTC,RC2 ;enable the RTC
CALL SDELAY
MOVLW 0x06 ;years register address for read
CALL SPI ;send address to DS1306
CALL SPI ;get the year
MOVWF PORTB ;save the year
BCF PORTC,RC2 ;disable RTC
MOVLW 0x20
MOVWF PORTD
```
41.

```
BSF PORTC,RC2 ;enable the RTC
CALL SDELAY
MOVLW 0x01 ;minutess register address for read
CALL SPI ;send address to DS1306
CALL SPI ;get the minutes
```

```

MOVWF PORTB ;save the minutes
CALL SPI ;get the hour
MOVWF PORTD ;save the hour
BCF PORTC,RC2 ;disable RTC
42. BSF PORTC,RC2 ;enable the RTC
MOVLW 0x80 ;seconds register address for write
CALL SPI ;send address
MOVLW 0x05 ;05 seconds
CALL SPI ;send seconds
MOVLW 0x15 ;15 minutes
CALL SPI ;send minutes
MOVLW 0x69 ;12-hour clock at 9 pm hour
CALL SPI ;send hour
BCF PORTC,RC2 ;disable RTC
43. BSF PORTC,RC2 ;enable the RTC
MOVLW 0x80 ;seconds register address for write
CALL SPI ;send address
MOVLW 0x19 ;19 seconds
CALL SPI ;send seconds
MOVLW 0x47 ;47 minutes
CALL SPI ;send minutes
MOVLW 0x22 ;24-hour clock at 22 hours
CALL SPI ;send hour
BCF PORTC,RC2 ;disable RTC
44. BSF PORTC,RC2 ;enable the RTC
MOVLW 0x84 ;date register address for write
102
CALL SPI ;send address
MOVLW 0x14 ;14th of the month
CALL SPI ;send day of the month
MOVLW 0x05 ;May
CALL SPI ;send month
MOVLW 0x09 ;2009
CALL SPI ;send year
BCF PORTC,RC2 ;disable RTC
45. Vbat is a non-rechargeable source. Vcc2 provides a trickle charge for a rechargeable
source.

```

SECTION 16.3: DS1306 RTC PROGRAMMING IN C

```

46. PORTCbits.RC2 = 1; //begin multi byte read
SDELAY(1);
SPI(0x00); //seconds register address
for(i=0;i<3;i++)
{
data[i] = SPI(0x00); //get time and save
}
PORTCbits.RC2 = 0; //end of multi byte read
//-- convert time and display HH:MM:SS AM/PM

```

```

BCDtoASCIIandSEND(data[2]); //the hour
BCDtoASCIIandSEND(data[1]); //the minute
BCDtoASCIIandSEND(data[0]); //the second
47. PORTCbits.RC2 = 1; //begin multi byte read
SDELAY(1);
SPI(0x06); //years register address
PORTB = SPI(0x00); //get year and send to PORTB
PORTCbits.RC2 = 0; //end of multi byte read
//-- convert time and display HH:MM:SS AM/PM
PORTD = 0x20; //the century
48. PORTCbits.RC2 = 1; //begin multi byte read
SDELAY(1);
SPI(0x01); //minutes register address
for(i=0;i<2;i++)
{
data[i] = SPI(0x00); //get time and save
}
PORTCbits.RC2 = 0; //end of multi byte read
//-- convert time and display HH:MM:SS AM/PM
PORTD = data[1]; //the hour
PORTB = data[0]; //the minute
Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 103
49. PORTCbits.RC2 = 1; //enable the RTC
SDELAY(1);
SPI(0x8F); //control register address
SPI(0x00); //clear WP bit for write
PORTCbits.RC2 = 0; //end of single-byte write
SDELAY(1);
PORTCbits.RC2 = 1; //begin multi byte write
SPI(0x80); //seconds register address
SPI(0x05); //05 seconds
SPI(0x15); //15 minutes
SPI(0x69); //12-hour clock at 9 pm hour
PORTCbits.RC2 = 0; //end multi byte write
50. PORTCbits.RC2 = 1; //enable the RTC
SDELAY(1);
SPI(0x8F); //control register address
SPI(0x00); //clear WP bit for write
PORTCbits.RC2 = 0; //end of single-byte write
SDELAY(1);
PORTCbits.RC2 = 1; //begin multi byte write
SPI(0x80); //seconds register address
SPI(0x19); //19 seconds
SPI(0x47); //47 minutes
SPI(0x22); //24-hour clock at 22 hours
PORTCbits.RC2 = 0; //end multi byte write
51. PORTCbits.RC2 = 1; //enable the RTC

```

```

SDELAY(1);
SPI(0x8F); //control register address
SPI(0x00); //clear WP bit for write
PORTCbits.RC2 = 0; //end of single-byte write
SDELAY(1);
PORTCbits.RC2 = 1; //begin multi byte write
SPI(0x84); //date register address
SPI(0x14); //14th of the month
SPI(0x05); //May
SPI(0x09); //2009
PORTCbits.RC2 = 0; //end multi byte write

```

52. The RTC does not keep track of the century on its own, since it goes from 00 to 99 for the year.

SECTION 16.4: ALARM AND INTERRUPT FEATURES OF THE DS1306

53. Output, low

54. Output

104

55. bits 0 and 1, Clear the WP bit and then set the AIE1 and AIE0 bits.

56. bit 2, Clear WP bit and then set the 1-Hz bit.

57. bit 0

58. bit 1

59. True

60. The options associated with Alarm1.

61. To make an external signal for hardware interrupt.

62. IRQF0 is an interrupt flag and AIE0 enables the flag to go out to INT0 pin

63. IRQF1 is an interrupt flag and AIE1 enables the flag to go out to INT1 pin

64. Set bit 2 of Control register at address 0x8F.

65. 0x8B

66. The IRQ1F goes high when the seconds match and the minutes and hours are set to 0x80

of Alarm1.

Instructor's Manual for "The PIC Microcontroller and Embedded Systems" 105

CHAPTER 17: MOTOR CONTROL: RELAY, PWM, DC, AND STEPPER MOTORS

SECTION 17.1: RELAYS AND OPTOISOLATORS

1. False

2. True

3. There is no coil, spring or mechanical contact

4. False

5. 4.167 mA

6. Motor control and telecommunications

7. size and speed

8. EM relay

9. True

10. False

SECTION 17.2: STEPPER MOTOR INTERFACING

- 11. 4 degrees
- 12. 48
- 13. 1001, 1100, 0110
- 14. 0110, 0011, 1001
- 15. 0011, 0110, 1100
- 16. 1100, 1001, 0011
- 17. The ULN2003 provides additional current for driving the motor, No
- 18. b
- 19. Slows the motor
- 20. Decrease the time delay between steps
- SECTION 17.3: DC MOTOR INTERFACING AND PWM**
- 21. Stepper motor
- 22. The higher the load, the higher the current draw
- 23. False
- 24. no-load
- 25. Speed control
- 26. Positioning
- 27. True
- 28. Pulse width modulation. It varies the time on which affects the speed of the motor
- 29. Vary the PWM
- 30. An optoisolator protects the microcontroller pin

106